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A  
C O U R S E  
O F  
M A T H E M A T I C S,

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IN TWO VOLUMES:

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COMPOSED, AND MORE ESPECIALLY DESIGNED  
FOR THE USE OF THE GENTLEMEN CADETS  
IN THE  
ROYAL MILITARY ACADEMY AT WOOLWICH.

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BY  
CHARLES HUTTON, LL.D. F.R.S.  
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THE FOURTH EDITION,  
ENLARGED AND CORRECTED.

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VOL. I.

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## P R E F A C E;

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A SHORT and Easy Course of the Mathematical Sciences has long been considered as a desideratum for the use of Students in the different schools of education: one that should hold a middle rank between the more voluminous and bulky collections of this kind, and the mere abstract and brief common-place forms, of principles and memorandums.

For long experience in all Seminaries of Learning, and particularly in the Royal Military Academy at Woolwich, has shewn, that such a work was very much wanted, and would prove a great and general benefit; as, for want of it, recourse has always been obliged to be had to a number of other books, of different authors; selecting a part from one and a part from another, as seemed most suitable to the purpose in hand, and rejecting the other parts—a practice which occasions much expense and trouble, in procuring and keeping such a number of odd volumes, of various modes of composition and form; besides wanting the benefit of uniformity and reference, which are found in a regular series of composition.

To remove these inconveniences, the Author of the present work has been induced, from time to time, to compose various parts of this Course of Mathematics; which the experience of many years' use in the Academy has enabled him to adapt and improve to the most useful form and quantity; for the benefit of instruction. And, to render that benefit more eminent and lasting, the Master-General of the Ordnance has been pleased to give it its present form, by ordering it to be enlarged and printed.

As this work has been composed expressly with the intention of adapting it to the purposes of academical education, it is not designed to hold out the expectation of new inventions or discoveries: but rather to collect and arrange the most useful principles in a convenient practical form, demonstrate them in a plain and concise way, and illustrate them

with suitable examples : rejecting whatever seem to be matters of mere curiosity ; and retaining only such parts and branches, as have a direct tendency and application to some useful purpose in life, especially in the military profession, for which the gentlemen educated at this Academy are intended.

As a work of such a nature must necessarily consist of matters which have, in a manner, become common property, and in a great measure are contained, in some shape or other, in most books of this kind, it will not be imputed to the author, as a crime, that he has availed himself of the materials of some of the best books on these sciences, from whence he may have extracted, or which he may have imitated ; whether they be any of his own former publications, or those of other authors.

It is, however, expected that something new may be found in many parts of these volumes ; as well in the matter, as in the arrangement and manner of demonstration ; especially in the geometry, which is made much more easy and simple ; and in the conic-sections, which are here treated in a manner at once new, easy, and natural ; so much so indeed, that all the propositions and their demonstrations, in the eclipse, are the very same, word for word, as those in the hyperbola, using only, in a very few places, the word *sum*, for the word *difference* : also in many of the mechanical and philosophical parts which follow, in the second volume. In the conic-sections, too, it may be observed, that the first theorem of each section only is proved from the cone itself, and all the rest of the theorems are deduced from the first, or from each other, in a very plain and simple manner.

*Royal Military Academy,* }  
July 3rd, 1798. }

Besides re-computing the examples, and rendering them more correct in the numbers, this edition is much enlarged in several places, and particularly by extending the tables of squares and cubes, square roots and cube roots, to 1000 numbers, which will be found of great use in many calculations ; also by the table of logarithms at the end of the first volume, and of logarithms, sines, and tangents, at the end of the second volume.

Sept. 1803.

# ARITHMETIC;

OR,

PART I. OF VOL. I.



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A

COURSE  
OF  
MATHEMATICS, &c.

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GENERAL PRINCIPLES.

1. QUANTITY, or MAGNITUDE, is any thing that will admit of increase or decrease; or that is capable of any sort of calculation or mensuration: such as, numbers, lines, space, time, motion, weight.

2. MATHEMATICS is the science which treats of all kinds of quantity whatever, that can be numbered or measured.—That part which treats of numbering is called *Arithmetic*; and that which concerns measuring, or figured extension, is called *Geometry*.—These two, which are conversant about multitude and magnitude, and are the foundation of all the other parts, are called *Pure* or *Abstract Mathematics*; because they investigate and demonstrate the properties of abstract numbers and magnitudes of all sorts. And when these two parts are applied to particular or practical subjects, they constitute the branches or parts called *Mixed Mathematics*.—Mathematics is also distinguished into *Speculative* and *Practical*; viz. *Speculative*, when it is concerned in discovering properties and relations; and *Practical*, when applied to practice and real use concerning physical objects.

## GENERAL PRINCIPLES.

3. In Mathematics are several general terms or principles ; such as, Definitions, Axioms, Propositions, Theorems, Problems, Lemmas, Corollaries, Scholiums, &c.

4. *A Definition* is the explication of any term or word in a science ; shewing the sense and meaning in which the term is employed.—Every Definition ought to be clear, and expressed in words that are common and perfectly well understood.

5. *A Proposition* is something proposed to be proved, or something required to be done ; and is accordingly either a Theorem or a Problem.

6. *A Theorem* is a demonstrative proposition ; in which some property is asserted, and the truth of it required to be proved. Thus, when it is said that, The sum of the three angles of any triangle, is equal to two right angles, this is a Theorem, the truth of which is demonstrated by Geometry.—A set or collection of such Theorems constitutes a *Theory*.

7. *A Problem* is a proposition or a question requiring something to be done ; either to investigate some truth or property, or to perform some operation. As, to find out the quantity or sum of all the three angles of any triangle, or to draw one line perpendicular to another.—*A Limited Problem* is that which has but one answer or solution. *An Unlimited Problem* is that which has innumerable answers. And a *Determinate Problem* is that which has a certain number of answers.

8. *Solution* of a Problem, is the resolution or answer given to it. *A Numerical or Numeral Solution*, is the answer given in numbers. *A Geometrical Solution*, is the answer given by the principles of Geometry. And a *Mechanical Solution*, is one which is gained by trials.

9. *A Lemma* is a preparatory proposition, laid down in order to shorten the demonstration of the main proposition which follows it.

10. *A Corollary*, or *Consecutary*, is a consequence drawn immediately from some proposition or other premises.

11. *A Scholium* is a remark or observation made on some foregoing proposition or premises.

12. *An Axiom*, or *Maxim*, is a self-evident proposition ; requiring no formal demonstration to prove the truth of it ; but is received and assented to as soon as mentioned. Such as, The whole of any thing is greater than a part of it : or, The whole is equal to all its parts taken together : or, Two quantities that are each of them equal to a third quantity, are equal to each other.

13. *A Postulate*, or *Petition*, is something required to be done, which is so easy and evident that no person will hesitate to allow it.

14. *An Hypothesis* is a supposition assumed to be true, in order to argue from, or to found upon it the reasoning and demonstration of some proposition.

15. *Demonstration* is the collecting the several arguments and proofs, and laying them together in proper order, to shew the truth of the proposition under consideration.

16. *A Direct, Positive, or Affirmative Demonstration*, is that which concludes with the direct and certain proof of the proposition in hand.—This kind of demonstration is most satisfactory to the mind; for which reason it is called sometimes an *Offensive Demonstration*.

17. *An Indirect, or Negative Demonstration*, is that which shews a proposition to be true, by proving that some absurdity would necessarily follow if the proposition advanced were false. This is also sometimes called *Reductio ad Absurdum*; because it shews the absurdity and falsehood of all suppositions contrary to that contained in the proposition.

18. *Method* is the art of disposing a train of arguments in a proper order, to investigate either the truth or falsity of a proposition, or to demonstrate it to others when it has been found out.—This is either Analytical or Synthetical.

19. *Analysis*, or the *Analytic Method*, is the art or mode of finding out the truth of a proposition, by first supposing the thing to be done, and then reasoning back, step by step, till we arrive at some known truth.—This is also called the *Method of Invention*, or *Resolution*; and is that which is commonly used in Algebra.

20. *Synthesis*, or the *Synthetic Method*, is the searching out truth, by first laying down some simple and easy principles, and pursuing the consequences flowing from them till we arrive at the conclusion.—This is also called the *Method of Composition*; and is the reverse of the Analytic method, as this proceeds from known principles to an unknown conclusion; while the other goes in a retrograde order, from the thing sought, considered as if it were true, to some known principle or fact. And therefore, when any truth has been found out by the Analytic method, it may be demonstrated by a process in the contrary order, by Synthesis.

## ARITHMETIC.

**A**RITHMETIC is the art or science of numbering ; being that branch of Mathematics which treats of the nature and properties of numbers.—When it treats of whole numbers, it is called *Vulgar*, or *Common Arithmetic*; but when of broken numbers, or parts of numbers; it is called *Fractions*.

*Unity*, or an *Unit*, is that by which every thing is called one ; being the beginning of number ; as, one man, one ball, one gun.

*Number* is either simply one, or a compound of several units ; as, one man, three men, ten men.

An *Integer*, or *Whole Number*, is some certain precise quantity of units ; as, one, three, ten.—These are so called as distinguished from *Fractions*, which are broken numbers, or parts of numbers ; as, one-half, two-thirds, or three-fourths.

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### NOTATION AND NUMERATION.

**N**O TATION, or **N**UMERATION, teaches to denote or express any proposed number, either by words or characters ; or to read and write down any sum or number.

The numbers in Arithmetic are expressed by the following ten digits, or Arabic numeral figures, which were introduced into Europe by the Moors, about eight or nine hundred years since ; viz. 1 one, 2 two, 3 three, 4 four, 5 five, 6 six, 7 seven, 8 eight, 9 nine, 0 cipher, or nothing. These characters or figures were formerly all called by the general name of *Ciphers*; whence it came to pass that the art of Arithmetic was then often called *Ciphering*. Also the first nine are called *Significant Figures*, as distinguished from the cipher, which is quite insignificant of itself.

Beside this value of those figures, they have also another, which depends on the place they stand in when joined together ; as in the following table :

Here, any figure in the first place, reckoning from right to left, denotes only its own simple value; but that in the second place, denotes ten times its simple value; and that in the third place, a hundred times its simple value; and so on; the value of any figure, in each successive place, being always ten times its former value.

Thus, in the number 1796, the 6 in the first place denotes only six units, or simply six; 9 in the second place signifies nine tens, or ninety; 7 in the third place, seven hundred; and the 1 in the fourth place, one thousand: so that the whole number is read thus, one thousand seven hundred and ninety-six.

As to the cipher, 0, though it signify nothing of itself, yet being joined on the right-hand side to other figures, it increases their value in the same ten-fold proportion: thus, 5 signifies only five; but 50 denotes 5 tens, or fifty; and 500 is five hundred; and so on.

For the more easily reading of large numbers, they are divided into periods and half-periods, each half-period consisting of three figures: the name of the first period being units; of the second, millions; of the third, millions of millions, or bi-millions, contracted to billions; of the fourth, millions of millions of millions, or tri-millions, contracted to trillions; and so on. Also the first part of any period is so many units of it, and the latter part so many thousands

## ARITHMETIC.

The following Table contains a summary of the whole doctrine.

Periods.	Quadrill.; Trillions; Billions; Millions; Units.
Half-per.	th. un. th. un. th. un. th. un. th. un.
Figures.	123,456; 789,098; 765,432; 101,234; 567,890

NUMERATION is the reading of any number in words that is proposed or set down in figures; which will be easily done by help of the following rule, deduced from the foregoing tablets and observations—viz.

Divide the figures in the proposed number, as in the summary above, into periods and half-periods; then begin at the left-hand side, and read the figures with the names set to them in the two foregoing tables.

## EXAMPLES.

Express in words the following numbers; viz.

34	15080	13405670
96	72003	47050023
180	109026	309025600
304	483500	4723507689
6134	2560639	274856390000
9028	7523000	6578600307024

NOTATION is the setting down in figures any number proposed in words; which is done by setting down the figures instead of the words or names belonging to them in the summary above; suppling the vacant places with ciphers where any words do not occur.

## EXAMPLES.

Set down in figures the following numbers:

Fifty-seven.

Two hundred eighty-six.

Nine thousand two hundred and ten.

Twenty-seven thousand five hundred and ninety-four.

Six hundred and forty thousand, four hundred and eighty-one.

Three millions, two hundred sixty thousand, one hundred and six.

Four

Four hundred and eight millions, two hundred and fifty-five thousand, one hundred and ninety-two.

Twenty-seven thousand and eight millions, ninety-six thousand two hundred and four.

Two hundred thousand and five hundred and fifty millions, one hundred and ten thousand, and sixteen.

Twenty-one billions, eight hundred and ten millions, sixty-four thousand, one hundred and fifty.

### OF THE ROMAN NOTATION.

THE Romans, like several other nations, expressed their numbers by certain letters of the alphabet. The Romans used only seven numeral letters, being the seven following capitals: viz. I for *one*; V for *five*; X for *ten*; L for *fifty*; C for *an hundred*; D for *five hundred*; M for *a thousand*. The other numbers they expressed by various repetitions and combinations of these, after the following manner:

1 = I		
2 = II	As often as any character is repeated, so many times is its value repeated.	
3 = III		
4 = IIII or IV	A less character before a greater diminishes its value.	
5 = V		
6 = VI	A less character after a greater increases its value,	
7 = VII		
8 = VIII		
9 = IX		
10 = X		
50 = L		
100 = C		
500 = D or CI	For every C annexed, this becomes 10 times as many.	
1000 = M or CI		
2000 = MM	For every C and I, placed one at each end, it becomes 10 times as much.	
5000 = <u>V</u> or CCI		
6000 = <u>VI</u>	A bar over any number increases it 1000 fold.	
10000 = <u>X</u> or CCII		
50000 = <u>L</u> or CCCI		
60000 = <u>LX</u>		
100000 = <u>C</u> or CCCII		
1000000 = <u>M</u> or CCCCCCII		
2000000 = <u>MM</u>		
&c,	&c.	

## EXPLANATION OF CERTAIN CHARACTERS.

THERE are various characters or marks used in Arithmetic, and Algebra, to denote several of the operations and propositions; the chief of which are as follow:

$+$  signifies *plus*, or addition.

$-$  - - *minus*, or subtraction.

$\times$  or  $\cdot$  - multiplication.

$\div$  - - division.

$::::$  - proportion.

$=$  - - equality.

$\sqrt{\phantom{x}}$  - - square root.

$\sqrt[3]{\phantom{x}}$  - - cube root, &c.

$\S$  - - diff. between two numbers when it is not known which is the greater.

Thus,

$5 + 3$ , denotes that 3 is to be added to 5.

$6 - 2$ , denotes that 2 is to be taken from 6.

$7 \times 3$ , or  $7 \cdot 3$ , denotes that 7 is to be multiplied by 3.

$8 \div 4$ , denotes that 8 is to be divided by 4.

$2 : 3 :: 4 : 6$ , shews that 2 is to 3 as 4 is to 6.

$6 + 4 = 10$ , shews that the sum of 6 and 4 is equal to 10.

$\sqrt{3}$ , or  $3^{\frac{1}{2}}$ , denotes the square root of the number 3.

$\sqrt[3]{5}$ , or  $5^{\frac{1}{3}}$ , denotes the cube root of the number 5.

$7^2$ , denotes that the number 7 is to be squared.

$8^3$ , denotes that the number 8 is to be cubed.

&c.

## OF ADDITION.

ADDITION is the collecting or putting of several numbers together, in order to find their *sum*, or the total amount of the whole. This is done as follows:

Set or place the numbers under each other, so that each figure may stand exactly under the figures of the same value, that

that is, units under units, tens under tens, hundreds under hundreds, &c. ; and draw a line under the lowest number, to separate the given numbers from their sum, when it is found.

—Then add up the figures in the column or row of units, and find how many tens are contained in their sum.—Set down exactly below, what remains more than those tens, or if nothing remains, a cipher, and carry as many ones to the next row as there are tens.—Next add up the second row, together with the number carried, in the same manner as the first. And thus proceed till the whole is finished, setting down the total amount of the last row.

### TO PROVE ADDITION.

*First Method.*—Begin at the top, and add together all the rows of numbers downwards; in the same manner as they were before added upwards; then if the two sums agree, it may be presumed the work is right.—This method of proof is only doing the same work twice over, a little varied.

*Second Method.*—Draw a line below the uppermost number, and suppose it cut off.—Then add all the rest of the numbers together in the usual way, and set their sum under the number that is to be proved.—Lastly, add this last found number and the uppermost line together; then if their sum be the same as that found by the first addition, it may be presumed the work is right.—This method of proof is founded on the plain axiom, that “ The whole is equal to all its parts taken together.”

*Third Method.*—Add the figures in the uppermost line together, and find how many nines are contained in their sum.—Reject those nines, and set down the remainder towards the right-hand directly even with the figures in the line, as in the annexed example.—Do the same with each of the proposed lines of numbers, setting all these excesses of nines in a column on the right-hand, as here 5, 5, 6. Then, if the excess of 9's in this sum, found as before, be equal to the excess of 9's in the total sum 18304, the work is right.—Thus, the sum of the right-hand column, 5, 5, 6, is 16, the excess of which above 9 is 7. Also the sum of the figures in the

### EXAMPLE I.

3497	5
6512	5
8295	6
—	—
18304	7
	—

Excess of nines.

the sum total, 18304, is 16, the excess of which above 9 is also 7, the same as the former \*.

## OTHER EXAMPLES.

2.	3.	4.
12345	12345	12345
67890	67890	876
98765	9876	9087
43210	543	56
12345	21	234
67890	9	1012
<hr/>	<hr/>	<hr/>
302445	90684	23610
<hr/>	<hr/>	<hr/>
290100	78339	11265
<hr/>	<hr/>	<hr/>
302445	90684	23610

\* This method of proof depends on a property of the number 9, which, except the number 3, belongs to no other digit whatever; namely, that "any number divided by 9, will leave the same remainder as the sum of its figures or digits divided by 9;" which may be demonstrated in this manner.

*Demonstration.* Let there be any number proposed, as 4658. This, separated into its several parts, becomes  $4000 + 600 + 50 + 8$ . But  $4000 = 4 \times 1000 = 4 \times (999 + 1) = 4 \times 999 + 4$ . In like manner  $600 = 6 \times 99 + 6$ ; and  $50 = 5 \times 9 + 5$ . Therefore the given number  $4658 = 4 \times 999 + 4 + 6 \times 99 + 6 + 5 \times 9 + 5 + 8 = 4 \times 999 + 6 \times 99 + 5 \times 9 + 4 + 6 + 5 + 8$ ; and  $4658 \div 9 = (4 \times 999 + 6 \times 99 + 5 \times 9 + 4 + 6 + 5 + 8) \div 9$ . But  $4 \times 999 + 6 \times 99 + 5 \times 9$  is evidently divisible by 9, without a remainder; therefore if the given number 4658 be divided by 9, it will leave the same remainder as  $4 + 6 + 5 + 8$  divided by 9. And the same, it is evident, will hold for any other number whatever.

In like manner, the same property may be shewn to belong to the number 3; but the preference is usually given to the number 9, on account of its being more convenient in practice.

Now, from the demonstration above given, the reason of the rule itself is evident; for the excess of 9's in two or more numbers being taken separately, and the excess of 9's taken also out of the sum of the former excesses, it is plain that this last excess must be equal to the excess of 9's contained in the total sum of all these numbers; all the parts taken together being equal to the whole. — This rule was first given by Dr. Wallis in his Arithmetic, published in the year 1657.

- Ex. 5. Add 3426; 9024; 5106; 8390; 1204, together. Anf. 27150.  
 6. Add 509267; 235809; 72910; 8392; 420; 21; and 9, together. Anf. 826828.  
 7. Add 2; 19; 817; 4298; 50916; 730205; 9120634, together. Anf. 9906891.  
 8. How many days are in the twelve calendar months? Anf. 365.  
 9. How many days are there from the 15th day of April to the 24th day of November, both days included? Anf. 224.  
 10. An army consisting of 52714 infantry\*, or foot, 5110 horse, 6250 dragoons, 3927 light-horse, 928 artillery, or gunners, 1410 pioneers, 250 sappers, and 406 miners: what is the whole number of men? Anf. 70995.
- 

## OF SUBTRACTION.

SUBTRACTION teaches to find how much one number exceeds another, called their *difference*, or the *remainder*, by taking the less from the greater. The method of doing which is as follows:

Place the less number under the greater, in the same manner as in Addition, that is, units under units, tens under tens, and so on; and draw a line below them.—Begin at the right hand, and take each figure in the lower line, or number, from the figure above it, setting down the remainder below it.—But if the figure in the lower line be greater than that above it, first borrow, or add, 10 to the upper one, and then take the lower figure from that sum, setting down the remainder, and carrying 1, for what was borrowed, to the next lower figure, with which proceed as before; and so on till the whole is finished.

---

\* The whole body of foot soldiers is denoted by the word *Infantry*; and all those that charge on horseback by the word *Cavalry*.—Some authors conjecture that the term *infantry* is derived from a certain Infanta of Spain, who, finding that the army commanded by the king her father had been defeated by the Moors, assembled a body of the people together on foot, with which she engaged and totally routed the enemy. In honour of this event, and to distinguish the foot soldiers, who were not before held in much estimation, they received the name of *Infantry*, from her own title of *Infanta*.

## TO PROVE SUBTRACTION.

ADD the remainder to the less number, or that which is just above it; and if the sum be equal to the greater or uppermost number, the work is right\*.

## EXAMPLES.

1.	2.	3.
From 5386427	From 5386427	From 1234567
Take 2164315	Take 4258792	Take 702973
<hr/>	<hr/>	<hr/>
Rem. 3222112	Rem. 1127635	Rem. 531594
<hr/>	<hr/>	<hr/>
Proof. 5386427	Proof. 5386427	Proof. 1234567
<hr/>	<hr/>	<hr/>

4. From 5231806 take 5073918. Anf. 157888.  
 5. From 7020914 take 2766809. Anf. 4254105.  
 6. From 8503602 take 574371. Anf. 7929231.

7. Sir Isaac Newton was born in the year 1642, and he died in 1727: how old was he at the time of his decease?

Anf. 85 years.

8. Homer was born 2530 years ago, and Christ 1797 years ago: then how long before Christ was the birth of Homer? Anf. 733 years.

9. Noah's flood happened about the year of the world 1656, and the birth of Christ about the year 4000: then how long was the flood before Christ? Anf. 2344 years.

10. The Arabian or Indian method of notation was first known in England about the year 1150: then how long is it since to this present year 1797? Anf. 647 years.

11. Gunpowder was invented in the year 1330: then how long was this before the invention of printing, which was in 1441? Anf. 111 years.

12. The mariner's compass was invented in Europe in the year 1302: then how long was that before the discovery of America by Columbus, which happened in 1492? Anf. 190 years.

---

\* The reason of this method of proof is evident; for if the difference of two numbers be added to the less, it must manifestly make up a sum equal to the greater.

## OF MULTIPLICATION.

MULTIPLICATION is a compendious method of Addition, teaching how to find the amount of any given number when repeated a certain number of times ; as, 4 times 6, which is 24.

The number to be multiplied, or repeated, is called the *Multiplicand*.—The number you multiply by, or number of repetitions, is the *Multiplier*.—And the number found, being the total amount, is called the *Product*.—Also, both the multiplier and multiplicand are, in general, named the *Terms* or *Factors*.

Before proceeding to any operations in this rule, it is necessary to learn off very perfectly the following Table of all the products of the first 12 numbers, commonly called the Multiplication Table, or sometimes Pythagoras's Table, from its inventor.

MULTIPLICATION TABLE.

1	2	3	4	5	6	7	8	9	10	11	12
2	4	6	8	10	12	14	16	18	20	22	24
3	6	9	12	15	18	21	24	27	30	33	36
4	8	12	16	20	24	28	32	36	40	44	48
5	10	15	20	25	30	35	40	45	50	55	60
6	12	18	24	30	36	42	48	54	60	66	72
7	14	21	28	35	42	49	56	63	70	77	84
8	16	24	32	40	48	56	64	72	80	88	96
9	18	27	36	45	54	63	72	81	90	99	108
10	20	30	40	50	60	70	80	90	100	110	120
11	22	33	44	55	66	77	88	99	110	121	132
12	24	36	48	60	72	84	96	108	120	132	144

*To multiply any Given Number by a Single Figure, or by any Number not more than 12.*

\* Set the multiplier under the units figure, or right-hand place, of the multiplicand, and draw a line below it.—Then, beginning at the right hand, multiply every figure in this by the multiplier.—Count how many tens there are in the product of every single figure, and set down the remainder directly under the figure that is multiplied; and if nothing remains, set down a cipher.—Carry as many units or ones, as there are tens counted, to the product of the next figures; and proceed in the same manner till the whole is finished.

#### EXAMPLE.

$$\begin{array}{r} \text{Multiply } 9876543210 \text{ the Multiplicand.} \\ \text{By } - - - 2 \text{ the Multiplier.} \\ \hline \text{19753086420 the Product.} \end{array}$$

*To multiply by a Number consisting of Several Figures.*

† Set the multiplier below the multiplicand, placing them as in Addition; namely, units under units, tens under tens, &c. drawing a line below it.—Multiply the whole of the multiplicand by each figure of the multiplier, as in the last article; setting

\* The reason of this rule is the same as for the process in Addition, in which 1 is carried for every 10, to the next place, gradually as the several products are produced, one after another, instead of setting them all down below each other, as in the annexed Example.

$$\begin{array}{r} 5678 \\ 4 \\ \hline 32 = 8 \times 4 \\ 280 = 70 \times 4 \\ 2400 = 600 \times 4 \\ 20000 = 5000 \times 4 \\ \hline 22712 = 5678 \times 4 \end{array}$$

† After having found the produce of the multiplicand by the first figure of the multiplier, as in the former case, the multiplier is supposed to be divided into parts, and the product is found for the second figure in the same manner: but as this figure stands in the place of tens, the product must be ten times its simple value; and therefore the first figure of this product must be set in the place of tens;

setting down a line of products for each figure in the multiplier, so as that the first figure of each line may stand straight under the figure multiplying by.—Add all the lines of products together, in the order as they stand, and their sum will be the answer or whole product required.

### TO PROVE MULTIPLICATION.

THERE are three different ways of proving Multiplication, which are as below :

*First Method.*—Make the multiplicand and multiplier change places, and multiply the latter by the former in the same manner as before. Then if the product found in this way be the same as the former, the number is right.

*Second Method.*—\* Cast all the 9's out of the sum of the figures in each of the two factors, as in Addition, and set down the remainders. Multiply these two remainders together, and cast the 9's out of the product, as also out of

tens; or, which is the same thing, directly under the figure multiplied by. And proceeding in this manner separately with all the figures of the multiplier, it is evident that we shall multiply all the parts of the multiplicand by all the parts of the multiplier, or the whole of the multiplicand by the whole of the multiplier: therefore these several products being added together, will be equal to the whole required product; as in the example annexed.

1234567      the multiplicand.  
                4567

$$\begin{array}{r}
 8641969 = 7 \text{ times the mult.} \\
 7407402 = 60 \text{ times ditto.} \\
 6172835 = 500 \text{ times ditto.} \\
 4938268 = 4000 \text{ times ditto.} \\
 \hline
 5638267489 = 4567 \text{ times ditto.}
 \end{array}$$

\* This method of proof is derived from the peculiar property of the number 9, mentioned in the proof of Addition, and the reason for the one may serve for that of the other. Another more ample demonstration of this rule may be as follows:—Let P and Q denote the number of 9's in the factors to be multiplied, and  $a$  and  $b$  what remain; then  $9P + a$  and  $9Q + b$  will be the numbers themselves, and their product is  $(9P \times 9Q) + (9P \times b) + (9Q \times a) + (a \times b)$ ; but the first three of these products are each a precise number of 9's, because their factors are so, either one or both: these therefore being cast away, there remains only  $a \times b$ ; and if the 9's be also cast out of this, the excess is the excess of 9's in the total product: but  $a$  and  $b$  are the excesses in the factors themselves, and  $a \times b$  is their product; therefore the rule is true.

the whole product or answer of the question, reserving the remainders of these last two, which remainders must be equal when the work is right.—*Note*, It is common to set the four remainders within the four angular spaces of a cross, as in the example below.

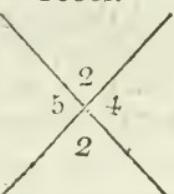
*Third Method.*—Multiplication is also very naturally proved by Division; for the product divided by either of the factors, will evidently give the other. But this cannot be practised till the rule of Division is learned.

## EXAMPLES.

$$\begin{array}{r} \text{Mult. } 3542 \\ \text{by } 6196 \\ \hline \end{array}$$

Proof.

$$\begin{array}{r} 21252 \\ 31878 \\ 3542 \\ 21252 \\ \hline \end{array}$$



21946232 Product.

$$\begin{array}{r} \text{or Mult. } 6196 \\ \text{by } 3542 \\ \hline \end{array}$$

$$\begin{array}{r} 12392 \\ 24784 \\ 30980 \\ 18588 \\ \hline \end{array}$$

21946232 Proof.

## OTHER EXAMPLES.

Multiply 123456789 by 3.	Anf. 370370367.
Multiply 123456789 by 4.	Anf. 493827156.
Multiply 123456789 by 5.	Anf. 617283945.
Multiply 123456789 by 6.	Anf. 740740734.
Multiply 123456789 by 7.	Anf. 864197523.
Multiply 123456789 by 8.	Anf. 987654312.
Multiply 123456789 by 9.	Anf. 111111101.
Multiply 123456789 by 11.	Anf. 1358024679.
Multiply 123456789 by 12.	Anf. 1481481468.
Multiply 302914603 by 16.	Anf. 4846633648.
Multiply 273580961 by 23.	Anf. 6292362103.
Multiply 402097316 by 195.	Anf. 78408976620.
Multiply 82164973 by 3027.	Anf. 248713373271.
Multiply 7564900 by 579.	Anf. 4380077100.
Multiply 8496427 by 874359.	Anf. 7428927415293.
Multiply 2760325 by 37672.	Anf. 102330768400.

## CONTRACTIONS IN MULTIPLICATION.

## I. When there are Ciphers in the Factors.

If the ciphers be at the right-hand of the numbers ; multiply the other figures only, and annex as many ciphers to the right-hand of the product, as are in both the factors.— When the ciphers are in the middle parts of the multiplier ; neglect them as before, only taking care to place the first figure of every line of products exactly under the figure multiplying with.

## EXAMPLES.

1.	2.
Mult. 9001635	Mult. 390720400
by - 70100	by - 406000
<hr/>	<hr/>
9001635	23443224
63011445	15628816
<hr/>	<hr/>
631014613500 Products	158632482400000

3. Multiply 81503600 by 7030. Ans. 572970308000.
4. Multiply 9030100 by 2100. Ans. 18963210000.
5. Multiply 8057069 by 70050. Ans. 564397683450.

## II. When the Multiplier is the Product of two or more Numbers in the Table ; then

\* Multiply by each of those parts separately, instead of the whole number at once.

## EXAMPLES.

1. Multiply 51307298 by 56, or 7 times 8.

$$\begin{array}{r}
 51307298 \\
 \times 7 \\
 \hline
 359151086 \\
 \times 8 \\
 \hline
 2873208688
 \end{array}$$

\* The reason of this rule is obvious enough ; for any number multiplied by the component parts of another, must give the same product as if it were multiplied by that number at once. Thus, in the 1st example, 7 times the product of 8 by the given number, makes 56 times the same number, as plainly as 7 times 8 makes 56.

2. Multiply 31704592 by 36. Anf. 1141365312.  
 3. Multiply 29753804 by 72. Anf. 2142273888.  
 4. Multiply 7128368 by 96. Anf. 684323328.  
 5. Multiply 160430800 by 103. Anf. 17326526400.  
 6. Multiply 61835720 by 1320. Anf. 81623150400.  
 7. There was an army composed of 104 \* battalions, each consisting of 500 men; what was the number of men contained in the whole? Anf. 52000.  
 8. A convoy of ammunition † bread, consisting of 250 waggons, and each waggon containing 320 loaves, having been intercepted and taken by the enemy; what is the number of loaves lost? Anf. 80000.
- 

### OF DIVISION.

DIVISION is a kind of compendious method of Subtraction, teaching to find how often one number is contained in another, or may be taken out of it; which is the same thing.

The number to be divided is called the *Dividend*.—The number to divide by, is the *Divisor*.—And the number of times the dividend contains the divisor, is called the *Quotient*.—Sometimes there is a *Remainder* left, after the division is finished.

The usual manner of placing the terms, is, the dividend in the middle, having the divisor on the left hand, and the quotient on the right, each separated by a curve line, as, to divide 12 by 4, the quotient is 3,

Dividend	12
Divisor 4)	4 subtr.
12	—
8	4 subtr.
4	—
0	—

‡ *Rule*.—Having placed the divisor before the dividend, as above directed, find how often the divisor is contained in as many figures of the dividend as are just necessary, and place the number on the right in the quotient.

Mul-

\* A battalion is a body of foot, consisting of 500, or 600, or 700 men, more or less.

† The ammunition bread is that which is provided for, and distributed to the soldiers; the usual allowance being a loaf of 6 pounds to every soldier, once in 4 days.

‡ In this way we resolve the dividend into parts, and find by trial how

Multiply the divisor by this number, and set the product under the figures of the dividend before-mentioned.—Subtract this product from that part of the dividend under which it stands, and bring down the next figure of the dividend, or more if necessary, to join on the right of the remainder.—Divide this number, so increased, in the same manner as before; and so on till all the figures are brought down and used.

*N. B.* If it be necessary to bring down more figures than one to any remainder, in order to make it as large as the divisor, or larger, a cipher must be set in the quotient for every figure so brought down more than one.

#### TO PROVE DIVISION.

\* MULTIPLY the quotient by the divisor ; to this product add the remainder, if there be any ; then the sum will be equal to the dividend when the work is right.

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how often the divisor is contained in each of those parts, one after another, and arranging the several figures of the quotient one after another, into one number.

When there is no remainder to a division, the quotient is the whole and perfect answer to the question. But when there is a remainder, it goes so much towards another time as it approaches to the divisor : so, if the remainder be half the divisor, it will go the half of a time more ; if the 4th part of the divisor, it will go one fourth of a time more ; and so on. Therefore, to complete the quotient, set the remainder at the end of it, above a small line, and the divisor below it, thus forming a fractional part of the whole quotient.

\* This method of proof is plain enough : for since the quotient is the number of times the dividend contains the divisor, the quotient multiplied by the divisor must evidently be equal to the dividend.

There are also several other methods sometimes used for proving Division, some of the most useful of which are as follow :

*Second Method.*—Subtract the remainder from the dividend, and divide what is left by the quotient ; so shall the new quotient from this last division be equal to the former divisor, when the work is right.

*Third Method.*—Add together the remainder and all the products of the several quotient figures by the divisor, according to the order in which they stand in the work ; and the sum will be equal to the dividend when the work is right.

## EXAMPLES.

1.	Quot.	2.	Quot.
3) 1234567	(411522	37) 12345678	(333666
12	mult. 3	111	37
—	—	—	—
3	1234566	124	2335662
3	add 1	111	1000998
—	—	—	rem. 36
4	1234567	135	—
3	—	111	12345678
—	Proof.	—	—
15		246	Proof.
15		222	—
—	—	—	—
6		247	
6		222	
—	—	—	—
7		258	
6		222	
—	—	—	—

Rem. 1

Rem. 36

3. Divide 73146085 by 4. Ans. 18286521 $\frac{1}{4}$ .  
 4. Divide 5317986027 by 7. Ans. 759712289 $\frac{4}{7}$ .  
 5. Divide 570196382 by 12. Ans. 47516365 $\frac{2}{12}$ .  
 6. Divide 74638105 by 37. Ans. 2017246 $\frac{3}{37}$ .  
 7. Divide 137896254 by 97. Ans. 1421610 $\frac{84}{97}$ .  
 8. Divide 35821649 by 764. Ans. 46886 $\frac{745}{764}$ .  
 9. Divide 72091365 by 5201. Ans. 13861 $\frac{304}{5201}$ .  
 10. Divide 4637064283 by 57606. Ans. 80496 $\frac{1797}{57606}$ .

11. Suppose 471 men are formed into ranks of 3 deep, what is the number in each rank? Ans. 157.

12. A party, at the distance of 378 miles from the head quarters, receive orders to join their corps in 18 days; what number of miles must they march each day to obey their orders? Ans. 21.

13. The annual revenue of a gentleman being 38330*l*; how much per day is that equivalent to, there being 365 days in the year? Ans. 104*l*.

## CONTRACTIONS IN DIVISION.

THERE are certain contractions in Division, by which the operation in particular cases may be performed in a shorter manner: as follows:

I. *Division by any Small Number*, not greater than 12, may be expeditiously performed, by multiplying and subtracting mentally, omitting to set down the work, except only the quotient immediately below the dividend.

## EXAMPLES.

3) 56103961

4) 52019675

5) 1370192

Quot. 18701320  $\frac{1}{3}$

6) 38072940

7) 81390627

8) 23718620

9) 43081962

11) 57014230

12) 27980813

II. \*When Ciphers are annexed to the Divisor; cut off those ciphers from it, and cut off the same number of figures from the right-hand of the dividend; then divide the remaining figures, as usual. And if there be any thing remaining after this division, place the figures cut off from the dividend to the right of it, and the whole will be the true remainder; otherwise, the figures cut off only will be the remainder.

## EXAMPLES.

1. Divide 3704196 by 20.

2,0) 370419,6

2. Divide 31086901 by 7100.

71,00) 310869,01 (4378  $\frac{3}{7} \frac{1}{10} \frac{0}{1}$   
284

Quot. 185209  $\frac{1}{2}$

—  
268

213 -

—  
556

497

—  
599

568

—  
31

3. Divide

\* This method is only to avoid a needless repetition of ciphers, which would happen in the common way. And the truth of the principle

3. Divide 7380964 by 23000.

Anf.  $320\frac{20964}{23000}$ .

4. Divide 2304109 by 5800.

Anf.  $397\frac{1509}{5800}$ .

*III. When the Divisor is the exact Product of two or more of the small Numbers not greater than 12:* \* Divide by each of those numbers separately, instead of the whole divisor at once.

*N. B.* There are commonly several remainders in working by this rule, one to each division; and to find the true or whole remainder, the same as if the division had been performed all at once, proceed as follows: Multiply the last remainder by the preceding divisor, or last but one, and to the product add the preceding remainder; multiply this sum by the next preceding divisor, and to the product add the next preceding remainder; and so on, till you have gone backward through all the divisors and remainders to the first. As in the example following:

#### EXAMPLES.

1. Divide 31046835 by 56 or 7 times 8.

$$\begin{array}{r}
 7) \underline{31046835} & & & 6 \text{ the last rem.} \\
 & \underline{-} & & \text{mult. 7 preced. divisor.} \\
 8) \underline{4435262} & -1 \text{ first rem.} & \underline{-} & \\
 & \underline{-} & & 42 \\
 & 554407 & -6 \text{ second rem. add 1 the 1st rem.} & \\
 & \underline{-} & & \underline{-} \\
 \text{Anf. } 554407\frac{43}{56} & & 43 \text{ whole rem.} &
 \end{array}$$

principle upon which it is founded, is evident; for, cutting off the same number of ciphers, or figures, from each, is the same as dividing each of them by 10, or 100, or 1000, &c. according to the number of ciphers cut off; and it is evident that as often as the whole divisor is contained in the whole dividend, so often must any part of the former be contained in a like part of the latter.

\* This follows from the second contraction in Multiplication, being only the converse of it; for the half of the third part of any thing, is evidently the same as the sixth part of the whole; and so of any other numbers.—The reason of the method of finding the whole remainder from the several particular ones, will best appear from the nature of Vulgar Fractions. Thus, in the first example above, the first remainder being 1, when the divisor is 7, makes  $\frac{1}{7}$ ; this must be added to the second remainder, 6, making  $6\frac{1}{7}$  to the divisor 8, or to be divided by 8. But  $6\frac{1}{7} = \frac{6 \times 7 + 1}{7} = \frac{43}{7}$ ; and this divided by 8 gives  $\frac{43}{7 \times 8} = \frac{43}{56}$ .

2. Divide

- |                            |   |
|----------------------------|---|
| 2. Divide 7014596 by 72.   | Anf. 97424 $\frac{5}{7}\frac{8}{2}$ .   |
| 3. Divide 5130652 by 132.  | Anf. 38868 $\frac{7}{13}\frac{6}{2}$ .  |
| 4. Divide 83016572 by 240. | Anf. 345902 $\frac{9}{24}\frac{2}{5}$ . |

*IV. Common Division may be performed more concisely, by omitting the several products, and setting down only the remainders; namely, multiply the divisor by the quotient figures as before, and, without setting down the product, subtract each figure of it from the dividend, as it is produced; always remembering to carry as many to the next figure as were borrowed before.*

## EXAMPLES.

1. Divide 304679 by 833.

$$\begin{array}{r}
 833) \ 3104679 \ (3727\frac{5}{8}\frac{8}{3}\frac{3}{5} \\
 6056 \\
 2257 \\
 5919 \\
 88
 \end{array}$$

2. Divide 79165238 by 238. Anf. 332627 $\frac{1}{2}\frac{1}{3}\frac{8}{5}$ .  
 3. Divide 29137062 by 5317. Anf. 5479 $\frac{5}{3}\frac{2}{1}\frac{1}{9}\frac{7}{7}$ .  
 4. Divide 62015735 by 7803. Anf. 7947 $\frac{3}{7}\frac{2}{8}\frac{9}{4}\frac{3}{5}$ .

## OF REDUCTION.

**REDUCTION** is the changing of numbers from one name or denomination to another, without altering their value.— This is chiefly concerned in reducing money, weights, and measures.

When the numbers are to be reduced from a higher name to a lower, it is called *Reduction Descending*; but when, contrarywise, from a lower name to a higher, it is *Reduction Ascending*.

Before proceeding to the rules and questions of Reduction, it will be proper to set down the usual Tables of money, weights, and measures, which are as follow:

## OF MONEY, WEIGHTS, AND MEASURES.

## TABLES OF MONEY\*.

2 Farthings	= 1 Halfpenny	$\frac{1}{2}$	<i>qrs</i>	<i>d</i>
4 Farthings	= 1 Penny	$\frac{1}{4}$	4 =	1 <i>s</i>
12 Pence	= 1 Shilling	$\frac{1}{12}$	48 =	12 = 1 <i>£</i>
20 Shillings	= 1 Pound	$\frac{1}{20}$	960 =	240 = 20 = 1

## PENCE TABLE.

<i>d</i>	<i>s</i>	<i>d</i>
20	is	1 8
30	—	2 6
40	—	3 4
50	—	4 2
60	—	5 0
70	—	5 10
80	—	6 8
90	—	7 6
100	—	8 4
110	—	9 2
120	—	10 0

## SHILLINGS TABLE.

<i>s</i>	<i>is</i>	<i>d</i>
1	—	12
2	—	24
3	—	36
4	—	48
5	—	60
6	—	72
7	—	84
8	—	96
9	—	108
10	—	120
11	—	132

TROY

\* £ denotes pounds, s shillings, and d denotes pence.

$\frac{1}{4}$  denotes 1 farthing, or one quarter of any thing.

$\frac{1}{2}$  denotes a halfpenny, or the half of any thing.

$\frac{3}{4}$  denotes 3 farthings, or three quarters of any thing.

The full weight and value of the English gold and silver coin, is as here below:

GOLD.	Value.	Weight.			SILVER.	Value.	Weight.		
		<i>£</i>	<i>s</i>	<i>d</i>			<i>s</i>	<i>d</i>	<i>dt</i>
A Guinea	1 1 0	5	9	$\frac{1}{2}$	A Crown	5 0	19	$\frac{1}{2}$	
Half-guinea	0 10 6	2	16	$\frac{3}{4}$	Half-crown	2 6	9	$\frac{1}{4}$	
Seven Shillings	0 7 0	1	19	$\frac{1}{6}$	Shilling	1 0	3	21	
Quarter-guinea	0 5 3	1	8	$\frac{1}{4}$	Sixpence	0 6	1	22	$\frac{1}{2}$

The usual value of gold is nearly 4*l* an ounce, or 2*d* a grain; and that of silver is nearly 5*s* an ounce. Also, the value of any quantity of gold, is to the value of the same weight of standard silver, nearly as 15 to 1, or more nearly as 15 and 1-14th to 1.

Pure gold, free from mixture with other metals, usually called fine gold, is of such purity of nature, that it will endure the fire without

## TROY WEIGHT\*.

— Grains	marked gr	gr	dwt
24 Grains make 1 Pennyweight	dwt	24 =	1 oz
20 Pennyweights 1 Ounce	oz	480 =	20 = 1 lb
12 Ounces	1 Pound	lb	5760 = 240 = 12 = 1

By this weight are weighed Gold, Silver, and Jewels.

## APOTHECARIES' WEIGHT.

Grains	- - marked gr
20 Grains make 1 Scruple	sc or 3
3 Scruples	1 Dram dr or 3
8 Drams	1 Ounce oz or 3
12 Ounces	1 Pound lb or th
gr	sc
20 =	1 dr
60 =	3 = 1 oz
480 =	24 = 8 = 1 lb
5760 =	288 = 96 = 12 = 1

This is the same as Troy weight, only having some different divisions. Apothecaries make use of this weight in compounding their Medicines; but they buy and sell their Drugs by Avoirdupois weight.

## AVOIR-

---

without wasting, though it be kept continually melted. But silver, not having the purity of gold, will not endure the fire like it: yet fine silver will waste but a very little by being in the fire any moderate time; whereas copper, tin, lead, &c. will not only waste, but may be calcined, or burnt to a powder.

Both gold and silver, in their purity, are so very soft and flexible (like new lead, &c.), that they are not so useful, either in coin or otherwise (except to beat into leaf gold or silver), as when they are alloyed, or mixed and hardened with copper or brass. And though most nations differ, more or less, in the quantity of such alloy, as well as in the same place at different times, yet in England the standard for gold and silver coin has been for a long time as follows—viz. That 22 parts of fine gold, and 2 parts of copper, being melted together, shall be esteemed the true standard for gold coin: And that 11 ounces and 2 pennyweights of fine silver, and 18 pennyweights of copper, being melted together, is esteemed the true standard for silver coin, called Sterling silver.

\* The original of all weights used in England, was a grain or corn of wheat, gathered out of the middle of the ear, and, being well dried, 32 of them were to make one pennyweight, 20 pennyweights

## AVOIRDUPOIS WEIGHT.

Drams	-	-	-	marked	<i>dr</i>			
16 Drams	-	-	make 1 Ounce	-	-	<i>oz</i>		
16 Ounces	-	-	-	1 Pound	-	-	<i>lb</i>	
28 Pounds	-	-	-	-	1 Quarter	-	-	<i>qr</i>
4 Quarters	-	-	-	1 Hundred Weight	-	<i>cwt</i>		
20 Hundred Weight	-	1 Ton	-	-	-	-	<i>ton</i>	

<i>dr</i>	<i>oz</i>	<i>lb.</i>	<i>qr</i>	<i>cwt</i>	<i>ton</i>
16 =	1	<i>lb.</i>			
256 =	16 =	1	<i>qr</i>		
7168 =	448 =	28 =	1	<i>cwt</i>	
28672 =	1792 =	112 =	4 =	1	<i>ton</i>
573440 =	35840 =	2240 =	80 =	20 =	1

By this weight are weighed all things of a coarse or droſſy nature, as Corn, Bread, Butter, Cheeſe, Fleſh, Grocery Wares, and ſome Liquids; also all Metals, except Silver and Gold.

	<i>oz</i>	<i>dwt</i>	<i>gr</i>	
Note, that 1 <i>lb</i> Avoirdupois = 14 11 15½ Troy.				
1 <i>oz</i>	-	-	= 0 18 5½	
1 <i>dr</i>	-	-	= 0 1 3½	

## LONG MEASURE.

3 Barley-corns	make 1 Inch	-	<i>In</i>	
12 Inches	-	1 Foot	-	<i>Ft</i>
3 Feet	-	1 Yard	-	<i>Yd</i>
6 Feet	-	1 Fathom	-	<i>Fth</i>
5 Yards and a half	-	1 Pole or Rod	-	<i>Pt</i>
40 Poles	-	1 Furlong	-	<i>Fur</i>
8 Furlongs	-	1 Mile	-	<i>Mile</i>
3 Miles	-	1 League	-	<i>Lea</i>
69½ Miles nearly	-	1 Degree	-	<i>Deg</i> or °.

weights one ounce, and 12 ounces one pound. But in later times, it was thought ſufficient to divide the ſame pennyweight into 24 equal parts, ſtill called grains, being the leaſt weight now in common uſe; and from thence the reſt are computed, as in the Tables above.

<i>In</i>	<i>Ft</i>	<i>Yd</i>	<i>Pt</i>	<i>Fur</i>	<i>Mile</i>
12 =	1				
36 =	3 =	1			
198 =	16 $\frac{1}{2}$ =	5 $\frac{1}{2}$ =	1	<i>Fur</i>	
7920 =	660 =	220 =	40 =	1	<i>Mile</i>
63360 =	5280 =	1760 =	320 =	8 =	1

## CLOTH MEASURE.

2 Inches and a quarter make	1 Nail	-	-	<i>Nl</i>
4 Nails	-	1 Quarer of Yard	-	<i>2r</i>
3 Quarters	-	1 Ell Flemish	-	<i>E F</i>
4 Quarters	-	1 Yard	-	<i>Yd</i>
5 Quarters	-	1 Ell English	-	<i>E E</i>
4 Quarters 1 $\frac{1}{3}$ Inc	-	1 Ell Scotch	-	<i>E S</i>

## SQUARE MEASURE.

144 Square Inches make	1 Sq Foot	-	<i>Ft</i>	
9 Square Feet	-	1 Sq Yard	-	<i>Yd</i>
.30 $\frac{1}{4}$ Square Yards	-	1 Sq Pole	-	<i>Pole</i>
40 Square Poles	-	1 Rood	-	<i>Rd</i>
4 Rods	-	1 Acre	-	<i>Acr</i>

<i>Sq Inc</i>	<i>Sq Ft</i>	<i>Sq Yd</i>	<i>Sq Pt</i>	<i>Rd</i>	
144 =	1				
1296 =	9 =	1			
39204 =	272 $\frac{1}{4}$ =	30 $\frac{1}{4}$ =	1	<i>Rd</i>	
1568160 =	10890 =	1210 =	40 =	1	<i>Acr</i>
6272640 =	43560 =	4840 =	160 =	4 =	1

By this measure, Land, Husbandmen and Gardeners' work are measured; also Artificers' work, such as Board, Glafs, Pavements, Plastering, Wainscoting, Tiling, Flooring, and every dimension of length and breadth only.

When three dimensions are concerned, namely, length, breadth, and depth or thickness, it is called cubic or solid measure, which is used to measure Timber, Stone, &c.

The cubic or solid Foot, which is 12 inches in length and breadth and thickness, contains 1728 cubic or solid inches, and 27 solid feet make one solid yard.

## DRY, or CORN MEASURE.

2 Pints make	1 Quart	-	-	<i>2t</i>
2 Quarts	-	1 Pottle	-	-
2 Pottles	-	1 Gallon	-	-
2 Gallons	-	1 Peck	-	-
4 Pecks	-	1 Bushel	-	-
8 Bushels	-	1 Quarter	-	-
5 Quarters	-	1 Wey, Load, or Ton	-	<i>Wey</i>
2 Weys	-	1 Last	-	-

*Pts Gal*

8 =	1	<i>Pec</i>		
16 =	2 =	1	<i>Bu</i>	
64 =	8 =	4 =	1	<i>2r</i>
512 =	64 =	32 =	8 =	1 <i>Wey</i>
2560 =	320 =	160 =	40 =	5 = 1 <i>Last</i>
5120 =	640 =	320 =	80 =	10 = 2 = 1

By this are measured all dry wares, as, Corn, Seeds, Roots, Fruits, Salt, Coals, Sand, Oysters, &c.

The standard Gallon dry-measure contains  $268\frac{4}{5}$  cubic or solid inches, and the Corn or Winchester bushel  $2150\frac{2}{3}$  cubic inches; for the dimensions of the Winchester bushel, by the Statute, are 8 inches deep, and  $18\frac{1}{2}$  inches wide or in diameter. But the Coal bushel must be  $19\frac{1}{4}$  inches in diameter; and 36 bushels, heaped up, make a London chaldron of coals, the weight of which is 3156 lb. Avoirdupois.

## ALE and BEER MEASURE.

2 Pints make	-	1 Quart	-	<i>2t</i>
4 Quarts	-	1 Gallon	-	<i>Gal</i>
36 Gallons	-	1 Barrel	-	<i>Bar</i>
1 Barrel and a half	-	1 Hogshead	-	<i>Hhd</i>
2 Barrels	-	1 Puncheon	-	<i>Pun</i>
2 Hogsheads	-	1 Butt	-	<i>Butt</i>
2 Butts	-	1 Tun	-	<i>Tun</i>

*Pts 2t*

2 =	1	<i>Gal</i>		
8 =	4 =	1	<i>Bar</i>	
288 =	144 =	36 = 1	<i>Hhd</i>	
432 =	216 =	54 = $1\frac{1}{2}$ = 1	<i>Butt</i>	
864 =	432 =	108 = 3 = 2 = 1		

Note, The Ale Gallon contains 282 cubic or solid Inches.

## WINE MEASURE.

2 Pints make	-	-	1 Quart	-	<i>2t</i>
4 Quarts	-	-	1 Gallon	-	<i>Gal</i>
42 Gallons	-	-	1 Tierce	-	<i>Tier</i>
63 Gallons or $1\frac{1}{2}$ Tier	-	-	1 Hogshead	-	<i>Hhd</i>
2 Tierces	-	-	1 Puncheon	-	<i>Pun</i>
2 Hogsheads	-	-	1 Pipe or Butt	-	<i>Pi</i>
2 Pipes or 4 Hhds	-	-	1 Tun	-	<i>Tun</i>

<i>Pts</i>	<i>2t</i>	
2 =	1	<i>Gal</i>
8 =	4 =	1 <i>Tier</i>
336 =	168 =	42 = 1 <i>Hhd</i>
504 =	252 =	63 = $1\frac{1}{2}$ = 1 <i>Pun</i>
672 =	336 =	84 = 2 = $1\frac{1}{2}$ = 1 <i>Pi</i>
1008 =	504 =	126 = 3 = 2 = $1\frac{1}{2}$ = 1 <i>Tun</i>
2016 =	1008 =	252 = 6 = 4 = 3 = 2 = 1

*Note*, By this are measured all Wines, Spirits, Strong-waters, Cyder, Mead, Perry, Vinegar, Oil, Honey, &c.

The Wine Gallon contains 231 cubic or solid inches. And it is remarkable, that the Wine and Ale Gallons have the same proportion to each other as the Troy and Avoirdupois Pounds have; that is, as one Pound Troy is to one Pound Avoirdupois, so is one Wine Gallon to one Ale Gallon.

## OF TIME.

60 Seconds or 60"	make	1 Minute	-	<i>M or</i>
60 Minutes	-	1 Hour	-	<i>Hr</i>
24 Hours	-	1 Day	-	<i>Day</i>
7 Days	-	1 Week	-	<i>Wk</i>
4 Weeks	-	1 Month	-	<i>Mo</i>
13 Months, 1 Day, 6 Hours, or 365 Days, 6 Hours	<i>1 Julian Year</i>	<i>Yr</i>		

<i>Sec</i>	<i>Min</i>		
60 =	1	<i>Hr</i>	
3600 =	60 =	1	<i>Day</i>
86400 =	1440 =	24 =	1 <i>Wk</i>
604800 =	10080 =	168 =	7 = 1 <i>Mo</i>
2419200 =	40320 =	672 =	28 = 4 = 1
31557600 =	525960 =	8766 =	365 $\frac{1}{4}$ = 1 <i>Year</i>

Wk Da Hr Mo Da Hr  
 Or 52 1 6 = 13 1 6 = 1 Julian Year  
 Da Hr M Sec  
 But 365 5 48 48 = 1 Solar Year.

---

### RULES FOR REDUCTION.

#### I. When the Numbers are to be reduced from a Higher Denomination to a Lower:

MULTIPLY the number in the highest denomination by as many as of the next lower make an integer, or 1, in that higher; to this product add the number, if any, which was in this lower denomination before, and set down the amount.

Reduce this amount in like manner, by multiplying it by as many as of the next lower make an integer of this, taking in the odd parts of this lower, as before. And so proceed through all the denominations, to the lowest; so shall the number last found be the value of all the numbers which were in the higher denominations, taken together\*.

#### EXAMPLE.

1. In 1234*l* 15*s* 7*d*, how many farthings?

<i>l</i>	<i>s</i>	<i>d</i>
1234	15	7
20		

---

24695 Shillings

12

---

296347 Pence

4

---

Answer 1185388 Farthings.

---

\* The reason of this rule is very evident; for pounds are brought into shillings by multiplying them by 20; shillings into pence, by multiplying them by 12; and pence into farthings, by multiplying by 4; and the reverse of this rule by Division.—And the same, it is evident, will be true in the reduction of numbers consisting of any denominations, whatever.

*II. When the Numbers are to be reduced from a Lower Denomination to a Higher:*

Divide the given number by as many as of that denomination make 1 of the next higher, and set down what remains, as well as the quotient.

Divide the quotient by as many as of this denomination make 1 of the next higher; setting down the new quotient, and remainder, as before.

Proceed in the same manner through all the denominations, to the highest; and the quotient last found, together with the several remainders, if any, will be of the same value as the first number proposed.

## EXAMPLES.

2. Reduce 1185388 farthings into pounds, shillings, and pence.

$$\begin{array}{r}
 4) \underline{\quad} 1185388 \\
 \underline{\quad} \\
 12) \underline{\quad} 296347 d \\
 \underline{\quad} \\
 2,0) \underline{\quad} 2469,5 s - 7d \\
 \underline{\quad} \\
 \text{Answer} \quad 1234 l \ 15s \ 7d
 \end{array}$$

3. Reduce 23l to farthings. Anf. 22080.  
 4. Reduce 337587 farthings to pounds, &c. Anf. 351l 13s 0 $\frac{1}{4}$ d.  
 5. How many farthings are in 35 guineas? Anf. 35280.  
 6. In 35280 farthings how many guineas? Anf. 35.  
 7. In 59lb 13dwts 5gr how many grains? Anf. 340157.  
 8. In 8012131 grains how many pounds, &c.? Anf. 1390lb 11oz 18dwt 19gr.  
 9. In 35 ton 17cwt 1qr 23lb 7oz 13dr how many drams? Anf. 20571005.  
 10. How many barley-corns will reach round the earth, supposing it, according to the best calculations, to be 25000 miles? Anf. 4752000000.  
 11. How many seconds are in a solar year, or 365 days 5hrs 48min 48sec? Anf. 31556928.  
 12. In a lunar month, or 29ds 12hrs 44min 3sec, how many seconds? Anf. 2551443.

## COMPOUND ADDITION.

COMPOUND ADDITION shews how to add or collect several numbers of different denominations into one sum.

**RULE.**—Place the numbers so that those of the same denomination may stand directly under each other, and draw a line below them. Add up the figures in the lowest denomination, and find, by Reduction, how many units, or ones, of the next higher denomination are contained in their sum.—Set down the remainder below its proper column, and carry those units or ones to the next denomination; which add up in the same manner as before.—Proceed thus through all the denominations, to the highest, whose sum, together with the several remainders, will give the answer sought.

The method of proof is the same as in Simple Addition.

## EXAMPLES OF MONEY.

1.			2.			3.			4.		
<i>l</i>	<i>s</i>	<i>d</i>	<i>l</i>	<i>s</i>	<i>d</i>	<i>l</i>	<i>s</i>	<i>d</i>	<i>l</i>	<i>s</i>	<i>d</i>
7	13	3	14	7	5	15	17	10	53	14	8
3	5	10 $\frac{1}{2}$	8	19	2 $\frac{1}{4}$	3	14	6	5	10	2 $\frac{3}{4}$
6	18	7	5	3	4 $\frac{1}{2}$	23	6	2 $\frac{3}{4}$	93	11	6
0	2	5 $\frac{3}{4}$	21	2	9	8	3	5	7	5	0
4	0	3	7	16	8 $\frac{1}{2}$	15	6	4	2	0	9
17	15	4 $\frac{1}{2}$	0	4	3	6	12	9 $\frac{1}{4}$	0	18	7
39	15	9 $\frac{3}{4}$									
32	2	6 $\frac{3}{4}$									
39	15	9 $\frac{3}{4}$									

5.			6.			7.			8.		
<i>l</i>	<i>s</i>	<i>d</i>	<i>l</i>	<i>s</i>	<i>d</i>	<i>l</i>	<i>s</i>	<i>d</i>	<i>l</i>	<i>s</i>	<i>d</i>
14	0	7 $\frac{1}{4}$	37	15	8	61	3	2 $\frac{1}{2}$	472	15	3
5	13	6	14	12	9 $\frac{3}{4}$	7	16	8	9	2	2 $\frac{1}{2}$
62	4	7	5	6	11	29	13	10 $\frac{3}{4}$	27	12	6 $\frac{1}{4}$
4	17	8	23	10	9 $\frac{1}{4}$	8	14	0	370	16	2 $\frac{1}{2}$
23	0	4 $\frac{3}{4}$	8	6	0	0	7	5 $\frac{1}{4}$	25	3	8
6	6	7	14	0	5 $\frac{1}{2}$	24	13	0	6	10	5 $\frac{1}{4}$
91	0	10 $\frac{1}{4}$	54	2	7 $\frac{1}{2}$	5	0	10 $\frac{3}{4}$	30	0	11 $\frac{3}{4}$

EXAM. 9. A nobleman, going out of town, is informed by his steward, that his butcher's bill comes to  $197l\ 13s\ 7\frac{1}{2}d$ ; his baker's to  $59l\ 5s\ 2\frac{3}{4}d$ ; his brewer's to  $85l$ ; his wine-merchant's to  $103l\ 13s$ ; to his corn-chandler is due  $75l\ 3d$ ; to his tallow-chandler and cheese-monger,  $27l\ 15s\ 11\frac{1}{4}d$ ; and to his tailor,  $55l\ 3s\ 5\frac{3}{4}d$ ; also for rent, servants' wages, and other charges,  $127l\ 3s$ : Now, supposing he would take  $100l$  with him, to defray his charges on the road, for what sum must he send to his banker? Anſ.  $830l\ 14s\ 6\frac{1}{4}d$ .

10. The strength of a regiment of foot, of 10 companies, and the amount of their subsistence\*, for a month of 30 days, according to the annexed Table, are required?

Numb.	Rank.	Subſiſtence for a Month.		
		<i>l</i>	<i>s</i>	<i>d</i>
1	Colonel	27	0	0
1	Lieutenant Colonel	19	10	0
1	Major	17	5	0
7	Captains	78	15	0
11	Lieutenants	57	15	0
9	Ensigns	40	10	0
1	Chaplain	7	10	0
1	Adjutant	4	10	0
1	Quarter-Master	5	5	0
1	Surgeon	4	10	0
1	Surgeon's Mate	4	10	0
30	Sergeants	45	0	0
30	Corporals	30	0	0
20	Drummers	20	0	0
2	Fifes	2	0	0
390	Private Men	292	10	0
507	Total	656	10	0

\* Subſiſtence Money, is the money paid to the soldiers weekly; which is short of their full pay, because their clothes, accoutrements, &c. are to be accounted for. It is likewise the money advanced to officers till their accounts are made up, which is commonly once a year, when they are paid their arrears. The following Table shews the full pay and ſubſiſtence of each rank on the English establishment:

## ARITHMETIC.

 DAILY PAY OF COMMISSIONED OFFICERS,  
 ACCORDING TO THE LATEST REGULATIONS.

RANK.	Horse Artillery & corps of C. Cm.	D. G. & F. Cav.	Foot Ar. & artillery	Regular Inf. and Fenc. Militia.	Life Guards,			Horse Guards.			Foot Guards.		
					Suboff.	Full Pay.	Suboff.	Full Pay.	Suboff.	Full Pay.	Suboff.	Full Pay.	Suboff.
Colonel (Comm.)	—	1 12	10 2	4 0	1	2	6	1 7 0	1 16 0	1 11 0	—	1 10 0	1 19 0
Colonel (en Second)	1 10 0	—	1 4 0	0	0	15 11 1	3 3 1	11 0	2 6	—	1 1 6 1	8	6
1st Lieut Col.	1 6 0	1 3	0 1 0	0	0	17 0	0	14	1 0 19 6	1 6 0	1 1 6	0	18 6 1
2d Ditto	—	—	—	0	0	15 0	0	14	—	0 18 0	1 4 0	4	6
1st Major	—	—	1 1 0	0	0	19 5	0	15	—	0 18 0	1 4 0	0	12 6 0
2d Ditto	—	—	—	—	—	—	—	—	—	—	—	—	6
Captain	—	—	0 15 0	0	0	14 7	0	10 0	9	5 0 12 1	0 16 0	6	6
Capt. Lieut.	—	—	0 10 0	0	0	9 0	0	7 0	0	8 2 0	11 0	0	6 0 0
1st Lieut.	—	—	0 9 0	0	0	9 0	0	6 0	5	0 11 6	0 15 0	0	7 10
2d Ditto	—	—	0 8 0	—	—	0 5 0	—	—	—	0 11 0	0 14 0	—	0 4 6 0
Cornet	—	—	0 8 0	—	—	0 4 8	—	—	—	—	—	0 3 0	4 0
Ensign	—	—	—	—	0 5 0	—	0 5 0	0 8 6	0 11 0	0 4 6 0	—	0 5 0	5 10
Adjutant	—	—	—	0 5 0	—	—	—	—	—	—	—	—	0 5 0
Pay-master	—	—	—	—	—	—	—	—	—	—	—	—	0 5 8
Quarter-master	—	—	0 5 0	—	—	0 5 8	—	—	—	0 6 6 0	8 6	—	0 12 6 0
Surgeon-major	—	—	0 12 0	0 11 4	0 10 0	0 9 5	—	—	—	—	—	—	0 15 0
Bat. Surg. or Surg.	—	—	—	—	—	—	0 6 0	0 8 0	0 9 0	0 12 0	0 7 6 0	10	0
Affl. Surg.	—	0 6 0	0 5 0	0 5 0	0 5 0	—	—	—	—	0 5 0	0 5 0	0	5 0
Veter. Surg.	—	0 8 0	0 8 0	0 8 0	0 8 0	—	—	—	—	—	—	—	—
Solicitor	—	—	—	—	—	—	—	—	—	—	—	—	—

N. B. When a Lieutenant, Ensign, Adjutant, or Quarter-master of Foot, Militia, Fencible Infantry, or Invalids, holds two commissions, one shilling per day is to be deducted from the above rates for each commission.

## EXAMPLES

## COMPOUND ADDITION.

35

## EXAMPLES OF WEIGHTS, MEASURES, &amp;c.

TROY WEIGHT.			APOTHECARIES' WEIGHT.								
1.	2.	3.	4.	oz	dr	fc	oz	dr	fc	gr	
lb oz dwt	oz dwt gr	lb oz dr fc	oz dr fc gr								
17 3 15	37 9 3	3 5 7 2	3 5 1 17								
4 6 3	9 5 3	13 7 3 0	7 3 2 5								
0 10 7	3 16 21	9 11 0 1	16 7 0 12								
9 5 0	17 7 8	0 9 1 2	9 5 1 5								
176 2 17	5 9 0	36 3 5 0	4 1 2 18								
23 11 12	3 0 19	5 8 6 1	36 4 1 14								

## AVOIRDUPOIS WEIGHT.

5.	6.	7.	8.				
lb	oz	dr	cwt qr lb	mls	fur	pls	yds feet inc
17 10 13	15 2	15	29 3 14				127 1 5
5 14 8	6 3	24	19 6 29				12 2 9
8 6 15	7 0	10	5 4 20				0 2 6
27 1 6	9 1	17	9 1 37				54 1 11
0 4 0	10 2	6	7 0 3				5 2 7
6 14 10	3 0	3	4 5 9				23 0 5

## CLOTH MEASURE.

9.	10.	11.	12.		
yds	qr nls	el en qrs nls	ac ro p	ac ro p	
26 3 1	270 1 0	225 3 37	19 0 16		
13 1 2	57 4 3	16 1 25	270 3 29		
6 2 0	8 2 1	9 0 13	9 1 3		
217 0 3	0 3 2	4 2 9	23 0 34		
9 1 0	10 1 0	42 1 19	7 2 16		
55 3 1	4 4 1	7 0 6	75 0 23		

## WINE MEASURE.

13.	14.	15.	16.
t	hds gal	hds gal pts	hds gal pts
13 3 15	15 6 1 5	17 37 3	29 43 5
8 1 37	7 16 3	4 13 5	7 9 2
4 2 26	29 23 7	3 6 2	14 16 6
25 0 12	3 15 1	5 14 0	6 8 1
3 1 9	16 8 0	12 9 6	57 13 4
72 3 21	4 36 6	8 42 4	5 6 0

## COMPOUND SUBTRACTION.

**C**OMPOUND SUBTRACTION shews how to find the difference between any two numbers of different denominations. To perform which, observe the following Rule:

## RULE.\*

PLACE the less number below the greater, so that those parts which are of the same denomination may stand directly under each other; and draw a line below them.—Begin at the right-hand, and subtract each number or part in the lower line, from the one just above it, and set the remainder straight below it.—But if any number in the lower line be greater than that above it, add so many to the upper number as make 1 of the next higher denomination; then take the lower number from the upper one thus increased, and set down the remainder. Carry the unit borrowed to the next number in the lower line; after which subtract this number from the one above it, as before; and so proceed till the whole is finished. Then the several remainders, taken together, will be the whole difference sought.

The method of Proof is the same as in Simple Subtraction,

## EXAMPLES OF MONEY.

	1.	2.	3.	4.
	<i>l s d</i>	<i>l s d</i>	<i>l s d</i>	<i>l s d</i>
From	79 17 8 $\frac{3}{4}$	103 3 2 $\frac{1}{2}$	57 0 10	251 13 0
Take	35 12 4 $\frac{1}{4}$	71 12 5 $\frac{3}{4}$	29 13 3 $\frac{1}{4}$	35 4 7 $\frac{3}{4}$
Rem.	44 5 4 $\frac{1}{2}$	31 10 8 $\frac{3}{4}$		
Proof	79 17 8 $\frac{3}{4}$	103 3 2 $\frac{1}{2}$		

5. What is the difference between  $73l\ 5\frac{1}{4}d$  and  $19l\ 13s\ 10d$ ?  
Ans.  $53l\ 6s\ 7\frac{3}{4}d$ .

\* The reason of this Rule will easily appear from what has been said in Simple Subtraction; for the borrowing depends on the same principle, and is only different as the numbers to be subtracted are of different denominations.

## COMPOUND SUBTRACTION.

37

Ex. 6. A lends to B 100*l*, how much is B in debt after A has taken goods of him to the amount of 73*l* 12*s* 4*d*?

Ans. 26*l* 7*s* 7*d*.

7. Suppose that my rent for half a year is 20*l* 12*s*, and that I have laid out for the land-tax 14*s* 6*d*, and for several repairs 1*l* 3*s* 3*d*, what have I to pay of my half year's rent?

Ans. 18*l* 14*s* 2*d*.

8. A trader, failing, owes to A 35*l* 7*s* 6*d*, to B 91*l* 13*s*  $\frac{1}{2}$ *d*, to C 53*l* 7*d*, to D 87*l* 5*s*, and to E 111*l* 3*s* 5*d*. When this happened, he had by him in cash, 23*l* 7*s* 5*d*, in wares 53*l* 11*s* 10*d*, in household furniture 63*l* 17*s* 7*d*, and in receivable book-debts 25*l* 7*s* 5*d*. What will his creditors lose by him, suppose these things delivered to them?

Ans. 212*l* 5*s* 6*d*.

## EXAMPLES OF WEIGHTS, MEASURES, &amp;c.

## TROY WEIGHT.

## APOTHECAR. WEIGHT.

1.

2.

3.

	lb	oz	dwt	gr	lb	oz	dwt	gr	lb	oz	dr	scr	gr
From	7	3	14	11	4	9	1	13	73	4	7	0	14
Take	3	7	5	19	3	7	16	12	26	7	2	1	16

Rem.

_____	_____	_____
-------	-------	-------

Proof

_____	_____	_____
-------	-------	-------

## AVOIRDUPOIS WEIGHT.

## LONG MEASURE.

4.

5.

6.

7.

c	qrs	lb	lb	oz	dr	m	fu	pl	yd	ft	in	
From	5	0	17	71	5	9	14	3	17	96	1	4
Take	3	2	11	14	6	14	3	7	9	41	2	7

Rem.

_____	_____	_____
-------	-------	-------

Proof

_____	_____	_____
-------	-------	-------

## CLOTH MEASURE.

## LAND MEASURE.

8.

9.

10,

11.

yd	qr	nl	yd	qr	nl	ac	ro	p	ac	ro	p	
From	17	2	1	9	0	2	17	1	14	57	1	16
Take	5	2	1	6	1	2	6	3	6	24	2	25

Rem.

_____	_____	_____
-------	-------	-------

Proof

_____	_____	_____
-------	-------	-------

## ARITHMETIC.

	WINE MEASURE.						ALE AND BEER MEASURE.					
	12.			13.			14.			15.		
	t	hd	gal	hd	gal	pt	hd	gal	pt	hd	gal	pt
From	17	2	23	5	0	4	14	29	3	71	16	5
Take	4	3	39	3	2	7	7	34	5	17	3	2
Rem.												
Proof												

	DRY MEASURE.						TIME.					
	16.			17.			18.			19.		
	la	qr	bu	bu	gal	pt	mo	we	da	ds	hrs	min
From	9	4	7	13	7	1	71	2	5	114	17	26
Take	3	7	2	7	3	4	14	3	0	75	12	35
Rem.												
Proof												

20. The line of defence in a certain polygon being 236 yards, and that part of it which is terminated by the curtain and shoulder being 146 yards 1 foot 4 inches; what then was the length of the face of the bastion? Ans. 89 yds 1 ft 8 in.

## COMPOUND MULTIPLICATION.

COMPOUND MULTIPLICATION shews how to find the amount of any given number of different denominations repeated a certain proposed number of times.

## RULE.

SET the multiplier under the lowest denomination of the multiplicand, and draw a line below it.—Multiply the number in the lowest denomination by the multiplier, and find how many units of the next higher denomination are contained in the product, setting down what remains.—In like manner multiply the number in the next denomination, and to the product carry or add the units, before found, and find how many units of the next higher denomination are in this amount,

amount, which carry in like manner to the next product, setting down the overplus.—Proceed thus to the highest denomination proposed; so shall the last product, with the several remainders, taken as one compound number, be the whole amount required.

The method of Proof, and the reason of the Rule, are the same as in Simple Multiplication.

## EXAMPLES OF MONEY.

1. To find the amount of 8 lb of Tea, at  $5s\ 8\frac{1}{2}d$  per lb.

$$\begin{array}{r}
 s \quad d \\
 5 \quad 8\frac{1}{2} \\
 \hline
 8 \\
 \hline
 \underline{\underline{£\ 2\ 5\ 8}} \text{ Answer.}
 \end{array}$$

		<i>l</i>	<i>s</i>	<i>d</i>
2.	4lb of Tea, at $7s\ 8d$ per lb.	Ansf.	1	10
3.	6lb of Butter, at $9\frac{1}{2}$ per lb.	Ansf.	0	4
4.	7lb of Tobacco, at $1s\ 8\frac{1}{2}d$ per lb.	Ansf.	0	11
5.	9cwt of Cheese, at $1l\ 11s\ 5d$ per cwt.	Ansf.	14	2
6.	10cwt of Cheese, at $2l\ 17s\ 10d$ per cwt.	Ansf.	28	18
7.	12cwt of Sugar, at $3l\ 7s\ 4d$ per cwt.	Ansf.	40	8

## CONTRACTIONS.

- I. If the multiplier exceed 12, multiply successively by its component parts, instead of the whole number at once,

## EXAMPLES.

1. 15 cwt of Cheese, at  $17s\ 6d$  per cwt.

$$\begin{array}{r}
 l \quad s \quad d \\
 0 \quad 17 \quad 6 \\
 \hline
 3 \\
 \hline
 2 \quad 12 \quad 6 \\
 \hline
 5 \\
 \hline
 \underline{\underline{13 \quad 2 \quad 6}} \text{ Answer.}
 \end{array}$$

		<i>l</i>	<i>s</i>	<i>d</i>
2.	20 cwt of Hops, at $4l\ 7s\ 2d$ per cwt.	Anf.	87	3
3.	24 tons of Hay, at $3l\ 7s\ 6d$ per ton.	Anf.	81	0
4.	45 ells of Cloth, at $1s\ 6d$ per ell.	Anf.	3	7

Ex. 5.

		<i>l</i>	<i>s</i>	<i>d</i>
Ex. 5.	63 gallons of Oil, at 2 <i>s</i> 3 <i>d</i> per gall.	Ansf.	7	1
6.	70 barrels of Ale, at 1 <i>l</i> 4 <i>s</i> per barrel.	Ansf.	84	0
7.	84 quarters of Oats, at 1 <i>l</i> 1 <i>s</i> 8 <i>d</i> per qr.	Ansf.	137	4
8.	96 quarters of Barley, at 1 <i>l</i> 3 <i>s</i> 4 <i>d</i> per qr.	Ansf.	112	0
9.	120 days' Wages, at 5 <i>s</i> 9 <i>d</i> per day.	Ansf.	34	10
10.	144 reams of Paper, at 1 <i>l</i> 3 <i>s</i> 4 <i>d</i> per ream.	Ansf.	96	0

II. If the multiplier cannot be exactly produced by the multiplication of simple numbers, take the nearest number to it, either greater or less, which can be so produced, and multiply by its parts, as before.—Then multiply the given multiplicand by the difference between this assumed number and the multiplier, and add the product to that before found when the assumed number is less than the multiplier, but subtract the same when it is greater.

## EXAMPLES.

1. 26 yards of Cloth, at 3s 0 $\frac{1}{4}$ d per yard.

$$\begin{array}{r}
 l \quad s \quad d \\
 0 \quad 3 \quad 0\frac{3}{4} \\
 \hline
 0 \quad 15 \quad 3\frac{3}{4} \\
 \hline
 3 \quad 16 \quad 6\frac{3}{4} \\
 3 \quad 0\frac{3}{4} \\
 \hline
 63 \quad 19 \quad 7\frac{1}{2}
 \end{array}
 \text{Answer.}$$

- |  | <i>l</i> | <i>s</i> | <i>d</i> |
|--|----------|----------|----------|
| 2. 29 quarters of Corn, at $2l\ 5s\ 3\frac{1}{4}d$ per qr. | Ansf.    | 65       | 12       |
| 3. 53 loads of Hay, at $3l\ 15s\ 2d$ per load.             | Ansf.    | 199      | 3        |
| 4. 79 bushels of Wheat, at $11s\ 5\frac{3}{4}d$ per bush.  | Ansf.    | 45       | 6        |
| 5. 94 casks of Beer, at $12s\ 2d$ per cask.                | Ansf.    | 57       | 3        |
| 6. 114 stone of Meat, at $15s\ 3\frac{3}{4}d$ per stone.   | Ansf.    | 87       | 5        |

## EXAMPLES OF WEIGHTS AND MEASURES.

1.				2.				3.				
lb	oz	dwt	gr	lb	oz	dr	fc	gr	cwt	qr	lb	oz
21	1	7	13	2	4	2	1	0	27	1	13	12
			4					7				12

# COMPOUND DIVISION.

41

4.				5.			6.		
mls	fu	pls	yds	yds	qrs	na	ac	ro	po
24	3	20	2	127	2	2	27	2	1
		6			8			9	

7.				8.				9.			
tuns	hhd	gal	pts	we	qr	bu	pe	mo	we	da	ho min
20	1	20	3	27	1	7	2	175	3	6	20 59
		5				7				11	

# COMPOUND DIVISION.

COMPOUND DIVISION teaches how to divide a number of several denominations by any given number, or into any number of equal parts.

## RULE.

PLACE the divisor on the left of the dividend, as in Simple Division.—Begin at the left-hand, and divide the number of the highest denomination by the divisor, setting down the quotient in its proper place.—If there be any remainder after this division, reduce it to the next lower denomination, which add to the number, if any, belonging to that denomination, and divide the sum by the divisor.—Set down again this quotient, reduce its remainder to the next lower denomination again, and so on through all the denominations to the last.

## EXAMPLES OF MONEY.

1. Divide 225*l* 2*s* 4*d* by 2.

$$\begin{array}{r} l \quad s \quad d \\ 2) \; 225 \quad 2 \quad 4 \\ \hline \end{array}$$

£112 11 2 the Quotient.

2. Divide

	<i>l</i>	<i>s</i>	<i>d</i>		<i>l</i>	<i>s</i>	<i>d</i>			
2.	Divide	751	14	$7\frac{3}{4}$	by	3.	Anf.	250	11	$6\frac{1}{2}$
3.	Divide	821	17	$9\frac{3}{4}$	by	4.	Anf.	205	9	$5\frac{1}{4}$
4.	Divide	2382	13	$5\frac{1}{2}$	by	5.	Anf.	476	10	$8\frac{1}{4}$
5.	Divide	28	2	$1\frac{1}{2}$	by	6.	Anf.	4	13	$8\frac{1}{4}$
6.	Divide	55	14	$0\frac{3}{4}$	by	7.	Anf.	7	19	$1\frac{3}{4}$
7.	Divide	6	5	4	by	8.	Anf.	0	15	8
8.	Divide	135	10	7	by	9.	Anf.	15	1	2
9.	Divide	21	18	4	by	10.	Anf.	2	3	10
10.	Divide	227	10	5	by	11.	Anf.	20	13	8
11.	Divide	1332	11	$8\frac{1}{2}$	by	12.	Anf.	111	0	$11\frac{1}{2}$

## CONTRACTIONS.

I. If the divisor exceed 12, find what simple numbers, multiplied together, will produce it, and divide by them separately, as in Simple Division.

## EXAMPLES.

1. What is Cheese per cwt, if 16 cwt cost 30*l* 18*s* 8*d*?

$$\begin{array}{r}
 l \quad s \quad d \\
 4) \ 30 \quad 18 \quad 8 \\
 \hline
 4) \ 7 \quad 14 \quad 8 \\
 \hline
 \text{£} \ 1 \quad 18 \quad 8 \text{ the Answer.}
 \end{array}$$

- |    | <i>l</i>   | <i>s</i>           | <i>d</i>           |
|----|--|--------------------|--------------------|
| 2. | If 20 cwt of Tobacco come to<br>120 <i>l</i> 10 <i>s</i> , what is that per cwt? } | Anf.               | 6 0 6              |
| 3. | Divide 57 <i>l</i> 3 <i>s</i> 7 <i>d</i> by 35.                                    | Anf.               | 1 12 8             |
| 4. | Divide 85 <i>l</i> 6 <i>s</i> by 72.   | Anf.               | 1 3 $8\frac{1}{4}$ |
| 5. | Divide 31 <i>l</i> 2 <i>s</i> $10\frac{1}{2}$ <i>d</i> by 99.                      | Anf.               | 0 6 $3\frac{1}{2}$ |
| 6. | At 18 <i>l</i> 18 <i>s</i> per cwt, how much per lb? Anf.                          | 0 3 $4\frac{1}{2}$ |                    |

II. If the divisor cannot be produced by the multiplication of small numbers, divide by the whole divisor at once, after the manner of Long-Division.

## EXAMPLES.

1. Divide  $74l\ 13s\ 6\frac{1}{4}d$  by 17.

$$17) \begin{array}{cccccc} l & s & d & l & s & d \\ 74 & 13 & 6\frac{1}{4} & (4 & 7 & 10\frac{1}{4} \end{array} \text{ Answer.}$$

$$\begin{array}{r}
 68 \\
 - 6 \\
 20 \\
 \hline
 133 \\
 119 \\
 \hline
 14 \\
 12 \\
 \hline
 174 \\
 170 \\
 \hline
 4 \\
 4 \\
 \hline
 17
 \end{array}$$

	<i>l</i>	<i>s</i>	<i>d</i>		<i>l</i>	<i>s</i>	<i>d</i>
2. Divide 23 15 $7\frac{1}{4}$ by 37.				Ansf.	0	12	$10\frac{1}{4}$
3. Divide 199 3 10 by 53.				Ansf.	3	15	2
4. Divide 675 12 6 by 138.				Ansf.	4	17	11
5. Divide 315 3 $10\frac{1}{4}$ by 365.				Ansf.	0	17	$3\frac{1}{4}$

## EXAMPLES OF WEIGHTS AND MEASURES.

- Divide 23lb 7oz 6dwts 12gr by 7.  
Ans. 3lb 4oz 9dwts 12gr.
  - Divide 13lb 1oz 2dr 0scr 10gr by 12.  
Ans. 1lb 1oz 0dr 2scr 10gr.
  - Divide 1061cwt 2qrs by 28. Ans. 37cwt 3qrs 18lb.
  - Divide 375mi 2fur 7po 2yds 1ft 2in by 39.  
Ans. 9mi 4fur 39po 0yds 2ft 8in.
  - Divide 571yds 2qrs 1na by 47. Ans. 12yds 0qr 2na.
  - Divide 51ac 2ro 3po by 51. Ans. 1ac 0ro 1po.
  - Divide 10tu 2hhds 17gall 2pi by 67. Ans. 39gall 6pi.
  - Divide 120la 1qr 1bu 2pe by 74.  
Ans. 1la 6qrs 1bu 3pe.
  - Divide 120mo 2we 3da 5ho 20min by 111.  
Ans. 1mo 0we 2da 10ho 12mi.

# GOLDEN

## GOLDEN RULE, OR, RULE OF THREE.

THE RULE OF THREE teaches how to find a fourth proportional to three numbers given : for which reason it is sometimes called the Rule of Proportion. It is called the Rule of Three, because three terms or numbers are given, to find a fourth. And because of its great and extensive usefulness, it is often called the Golden Rule.

This Rule is usually considered as of two kinds, namely, Direct, and Inverse.

The Rule of Three Direct, is that in which more requires more, or less requires less. As in this : if 3 men dig 21 yards of trench in a certain time, how much will 6 men dig in the same time ? Here more requires more, that is, 6 men, which are more than 3 men, will also perform more work, in the same time. Or when it is thus : if 6 men dig 42 yards, how much will 3 men dig in the same time ? Here, then, less requires less, or 3 men will perform proportionably less work than 6 men, in the same time. In both these cases, then, the Rule, or the Proportion, is Direct ; and the stating must be

thus, As 3 : 21 :: 6 : 42,

or thus, As 6 : 42 :: 3 : 21.

But the Rule of Three Inverse, is when more requires less, or less requires more. As in this : if 3 men dig a certain quantity of trench in 14 hours, in how many hours will 6 men dig the like quantity ? Here it is evident that 6 men, being more than 3, will perform an equal quantity of work in less time, or fewer hours. Or thus : if 6 men perform a certain quantity of work in 7 hours, in how many hours will 3 men perform the same ? Here less requires more, for 3 men will take more hours than 6 to perform the same work. In both these cases, then, the Rule, or the Proportion, is Inverse ; and the stating must be

thus, As 6 : 14 :: 3 : 7,

or thus, As 3 : 7 :: 6 : 14.

And in all these statings, the fourth term is found, by multiplying the 2d and 3d terms together, and dividing the product by the 1st term.

Of the three given numbers ; two of them contain the supposition, and the third a demand. And for stating and working questions of these kinds, observe the following general Rule :

## R U L E .

STATE the question, by setting down in a straight line the three given numbers, in the following manner, viz. so that the 2d term be that number of supposition which is of the same kind that the answer or 4th term is to be; making the other number of supposition the 1st term, and the demanding number the 3d term, when the question is in direct proportion; but contrariwise, the other number of supposition the 3d term, and the demanding number the 1st term, when the question has inverse proportion.

Then, in both cases, multiply the 2d and 3d terms together, and divide the product by the 1st, which will give the answer, or 4th term sought, of the same denomination as the second term.

*Note*, If the first and third terms consist of different denominations, reduce them both to the same: and if the second term be a compound number, it is mostly convenient to reduce it to the lowest denomination mentioned.—If, after division, there be any remainder, reduce it to the next lower denomination, and divide by the same divisor as before, and the quotient will be of this last denomination. Proceed in the same manner with all the remainders, till they be reduced to the lowest denomination which the second term admits of, and the several quotients taken together will be the answer required.

*Note* also, The reason for the foregoing Rules will appear when we come to treat of the nature of Proportions.—Sometimes also two or more statings are necessary, which may always be known from the nature of the question.

## E X A M P L E S .

1. If 8 yards of Cloth cost 1*l* 4*s*, what will 96 yards cost?

yds 1 s      yds 1 s  
As 8 : 1 4 :: 96 : 14 8 the Answer.

$$\begin{array}{r}
 20 \\
 \hline
 24 \\
 96 \\
 \hline
 144 \\
 216 \\
 \hline
 8) \underline{2304} \\
 2,0) \underline{28,8s} \\
 \hline
 \underline{\underline{\text{£} 14 8 Answer.}}
 \end{array}$$

Ex. 2. An engineer having raised 100 yards of a certain work in 24 days with 5 men; how many men must he employ to finish a like quantity of work in 15 days?

$$\begin{array}{rcccl} \text{ds} & \text{men} & \text{ds} & \text{men} \\ \text{As} & 15 : 5 & :: & 24 : 8 \text{ Ans.} \\ & & & 5 \end{array}$$

$$\begin{array}{rcl} 15) & 120 & (8 \text{ Answer.} \\ & 120 & \end{array}$$

3. What will 72 yards of Cloth cost, at the rate of 9 yards for  $5l\ 12s$ ? Ans.  $44l\ 16s$ .

4. A person's annual income being  $146l$ ; how much is that per day? Ans. 8s.

5. If 3 paces or common steps of a certain person be equal to 2 yards; how many yards will 160 of his paces make? Ans. 106 yds 2ft.

6. What length must be cut off a board, that is 9 inches board, to make a square foot, or as much as 12 inches in length and 12 in breadth contains? Ans. 16 inches.

7. If 750 men require 22500 rations of bread for a month; how many rations will a garrison of 1200 men require? Ans. 36000.

8. If 7 cwt 1 qr of sugar cost  $26l\ 10s\ 4d$ ; what will be the price of 43 cwt 2 qrs? Ans.  $159l\ 2s$ .

9. The clothing of a regiment of foot of 750 men amounting to  $2831l\ 5s$ ; what will the clothing of a body of 3500 men amount to? Ans.  $13212l\ 10s$ .

10. How many yards of matting, that is 2ft 6 in broad, will cover a floor that is 27 feet long and 20 feet broad? Ans. 72 yards.

11. What is the value of 6 bushels of coals, at the rate of  $1l\ 14s\ 6d$  the chaldron? Ans. 5s 9d.

12. If 6352 stones of 3 feet long complete a certain quantity of walling; how many stones of 2 feet long will raise a like quantity? Ans. 9528.

13. What must be given for a piece of silver weighing 73lb 5 oz 15 dwts, at the rate of 5s 9d per ounce? Ans.  $253l\ 10s\ 0\frac{3}{4}d$ .

14. A garrison of 536 men having provision for 12 months; how long will those provisions last, if the garrison be increased to 1124 men? Ans. 174 days and  $\frac{6\frac{1}{4}}{11\frac{1}{4}}$ .

15. What will be the tax upon  $763l\ 15s$ , at the rate of 3s 6d per pound sterling? Ans.  $133l\ 13s\ 1\frac{1}{2}d$ .

16. A certain work being raised in 12 days, by working 4 hours each day; how long would it have been in raising by working 6 hours per day? Anf. 8 days.

17. What quantity of corn can I buy for 90 guineas, at the rate of 6s the bushel? Anf. 39 qrs 3 bu.

18. A person, failing in trade, owes in all 977l; at which time he has, in money, goods, and recoverable debts, 420l 6s 3½d; now supposing these things delivered to his creditors, how much will they get per pound? Anf. 8s 7½d.

19. A plain of a certain extent having supplied a body of 3000 horse with forage for 18 days; then how many days would the same plain have supplied a body of 2000 horse?

Anf. 27 days.

20. Suppose a gentleman's income is 500 guineas a year, and that he spends 19s 7d per day, one day with another; how much will he have saved at the year's end?

Anf. 167l 12s 1d.

21. What cost 30 pieces of lead, each weighing 1 cwt 12lb, at the rate of 16s 4d the cwt? Anf. 27l 2s 6d.

22. The governor of a besieged place having provision for 54 days, at the rate of 1½lb of bread; but being desirous to prolong the siege to 80 days, in expectation of succour, in that case what must the ration of bread be? Anf. 1⅓lb.

23. At half a guinea per week, how long can I be boarded for 20 pounds? Anf. 38½ wks.

24. How much will 75 chaldrons 7 bushels of coals come to, at the rate of 1l 13s 6d per chaldron?

Anf. 125l 19s 0½d.

25. If the penny loaf weigh 9 ounces when the bushel of wheat costs 6s 3d, what ought the penny loaf to weigh when the wheat is at 8s 2½d? Anf. 6 oz 13⅔ dr.

26. How much a year will 173 acres 2 roods 14 poles of land give, at the rate of 1l 7s 8d per acre?

Anf. 240l 2s 7½d.

27. To how much amounts 172 pieces of lead, each weighing 3 cwt 2 qrs 17½ lb, at 8l 17s 6d per fother of 19½ cwt?

Anf. 286l 4s 4½d.

28. How many yards of stuff, of 3 qrs wide, will line a cloak that is 1¾ yards in length and 3½ yards wide?

Anf. 8 yds 0 qrs 2²/₃ nl.

29. If 5 yards of cloth cost 14s 2d, what must be given for 9 pieces, containing each 21 yards 1 quarter?

Anf. 27l 1s 10½d.

30. If a gentleman's estate be worth 2107l 12s a year; what may he spend per day, to save 500l in the year?

Anf. 4l 8s 1⅓d.

31. Wanting

31. Wanting just an acre of land cut off from a piece which is  $13\frac{1}{2}$  poles in breadth, what length must the piece be?

Anf. 11 po 4 yds 2 ft  $0\frac{1}{27}$  in.

32. At  $13s 2\frac{1}{2}d$  per yard, what is the value of a piece of cloth containing  $52\frac{3}{4}$  ells English? Anf.  $43l 8s 5\frac{3}{4}d$ .

33. If the carriage of 5 cwt 14 lb for 96 miles be  $1l 12s 6d$ ; how far may I have 3 cwt 1 qr carried for the same money?

Anf.  $151m 3fur 3\frac{1}{3}pol$ .

34. Bought a silver tankard, weighing 1 lb 7 oz 14 dwts; what did it cost me at  $6s 4d$  the ounce? Anf.  $6l 4s 9\frac{1}{3}d$ .

35. What is the half year's rent of 547 acres of land, at  $15s 6d$  the acre? Anf.  $211l 19s 3d$ .

36. A wall that is to be built to the height of 27 feet, was raised 9 feet high by 12 men in 6 days; then how many men must be employed to finish the wall in 4 days, at the same rate of working? Anf. 36 men.

37. What will be the charge of keeping 11 horses for a year, at the rate of  $11\frac{1}{2}d$  per day for each horse?

Anf.  $192l 7s 8\frac{1}{2}d$ .

38. If 15 ells of stuff that is  $\frac{3}{4}$  yard wide cost  $37s 6d$ ; what will 40 ells, of the same goodness, cost, being yard wide?

Anf.  $6l 13s 4d$ .

39. How many yards of paper that is 30 inches wide, will hang a room that is 20 yards in circuit and 9 feet high?

Anf. 72 yds.

40. If a gentleman's estate be worth  $384l 16s$  a year, and the land-tax be assessed at  $2s 9\frac{1}{2}d$  per pound, what is his net annual income?

Anf.  $331l 1s 9\frac{1}{2}d$ .

41. The circumference of the earth is about 25000 miles; at what rate per hour is a person at the middle of its surface carried round, one whole rotation being made in 23 hours 56 minutes?

Anf.  $1044\frac{8}{15}\frac{1}{6}$  miles.

42. If a person drink 20 bottles of wine per month, when it costs  $8s$  a gallon; how many bottles per month may he drink, without increasing the expense, when wine costs  $10s$  the gallon?

Anf. 16 bottles.

43. What cost 43 qrs 5 bushels of corn, at  $1l 8s 6d$  the quarter?

Anf.  $62l 3s 3\frac{3}{4}d$ .

44. How many yards of canvas that is ell wide, will line 20 yards of say that is 3 quarters wide?

Anf. 12 yds.

45. If an ounce of gold cost 4 guineas, what is the value of a grain?

Anf.  $2\frac{1}{2}d$ .

46. If 3 cwt of tea cost  $40l 12s$ ; at how much a pound must it be retailed, to gain  $10l$  by the whole?

Anf.  $3\frac{4}{5}s$ .

## COMPOUND PROPORTION.

**C**OMPOUND PROPORTION teaches how to resolve such questions as require two or more statings by Simple Proportion; and that, whether they be Direct or Inverse.

In these questions, there is always given an odd number of terms, either five, or seven, or nine, &c. These are distinguished into terms of supposition, and terms of demand, there being always one term more of the former than of the latter, which is of the same kind with the answer sought.

## R U L E .

**S**ET down in the middle place that term of supposition which is of the same kind with the answer sought.—Take one of the other terms of supposition, and one of the demanding terms which is of the same kind with it: then place one of them for a first term, and the other for a third, according to the directions given in the Rule of Three.—Do the same with another term of supposition, and its corresponding demanding term; and so on if there be more terms of each kind; setting the numbers under each other which fall all on the left-hand side of the middle term, and the same for the others on the right-hand side.—Then, to work

*By several Operations.*—Take the two upper terms and the middle term, in the same order as they stand, for the first Rule-of-Three question to be worked, whence will be found a fourth term. Then take this fourth number, so found, for the middle term of a second Rule-of-Three question, and the next two under terms in the general stating, in the same order as they stand, finding a fourth term for them. And so on, as far as there are any numbers in the general stating, making always the fourth number resulting from each simple stating to be the second term of the next following one. So shall the last resulting number be the answer to the question.

*By one Operation.*—Multiply together all the terms standing under each other, on the left-hand side of the middle term; and in like manner multiply together all those on the right-hand side of it. Then multiply the middle term by the latter product, and divide the result by the former product; so shall the quotient be the answer sought.

## EXAMPLES.

1. How many men can complete a trench of 135 yards long in 8 days, when 16 men can dig 54 yards in 6 days?

### *General Stating.*

yds	54 : 16 men :: 135 yds
days	8                        6 days
	<hr/>
	432                        810
	<hr/>
	16
	<hr/>
	4860
	<hr/>
	81                        men
432)	12960 (30 Anf. by one operat.
	<hr/>
	1296
	<hr/>
	0

*The same by two Operations.*

1st.	2d.
$\begin{array}{r} \text{As } 54 : 16 :: 135 : 40 \\ \hline 16 \\ 810 \\ 135 \\ \hline 54) \ 2160 \ (40 \\ 216 \\ \hline 0 \end{array}$	$\begin{array}{r} \text{As } 8 : 40 :: 6 : 30 \\ \hline 6 \\ 8) \ 240 \ (30 \text{ Ans.} \\ 24. \\ \hline 0 \end{array}$

2. If  $100l$  in one year gain  $5l$  interest, what will be the interest of  $750l$  for 7 years? Anf.  $262l\ 10s.$

3. If a family of 9 persons expend 120*l* in 8 months; how much will serve a family of 24 people 16 months?

4. If 27s be the wages of 4 men for 7 days; what will be the wages of 14 men for 10 days? Anf. 67 15s

5. If a footman travel 130 miles in 3 days, when the days are 12 hours long; in how many days, of 10 hours each, may he travel 360 miles? Anf.  $9\frac{6}{7}$  days.

### Ex. 6.

**Ex. 6.** If 120 bushels of corn can serve 14 horses 56 days ; how many days will 94 bushels serve 6 horses ?

Anf.  $102\frac{1}{5}$  days.

**7.** If 3000lb of beef serve 340 men 15 days ; how many lbs will serve 120 men for 25 days ? Anf. 1764lb  $11\frac{5}{7}$  oz.

**8.** If a barrel of beer be sufficient to last a family of 7 persons 12 days ; how many barrels will be drank by 14 persons in the space of a year ? Anf.  $60\frac{5}{6}$  barrels.

**9.** If 248 men, in 5 days, of 11 hours each, can dig a trench 230 yards long, 3 wide, and 2 deep ; in how many days, of 9 hours long, will 24 men dig a trench of 420 yards long, 5 wide, and 3 deep ? Anf.  $288\frac{5}{7}$  days.

## OF VULGAR FRACTIONS.

A FRACTION, or broken number, is an expression of a part, or some parts, of something considered as a whole.

It is denoted by two numbers, placed one below the other, with a line between them :

Thus,  $\frac{3}{4}$  numerator } which is named 3-fourths.

The Denominator, or number placed below the line, shews how many equal parts the whole quantity is divided into ; and represents the Divisor in Division.—And the Numerator, or number set above the line, shews how many of these parts are expressed by the Fraction : being the remainder after division.—Also, both these numbers are, in general, named the Terms of the Fraction.

Fractions are either Proper, Improper, Simple, Compound, or Mixed.

A Proper Fraction, is when the numerator is less than the denominator ; as,  $\frac{1}{2}$ , or  $\frac{2}{3}$ , or  $\frac{1}{3}$ , &c.

An Improper Fraction, is when the numerator is equal to, or exceeds, the denominator ; as,  $\frac{3}{3}$ , or  $\frac{5}{4}$ , or  $\frac{7}{5}$ , &c.

A Simple Fraction, is a single expression, denoting any number of parts of the integer ; as,  $\frac{2}{3}$ , or  $\frac{3}{4}$ .

A Compound Fraction, is the fraction of a fraction, or several fractions connected with the word *of* between them ; as,  $\frac{1}{2}$  of  $\frac{2}{3}$ , or  $\frac{3}{5}$  of  $\frac{5}{6}$  of 3, &c.

A Mixed Number, is composed of a whole number and a fraction together ; as,  $3\frac{1}{4}$ , or  $12\frac{4}{5}$ , &c.

A whole or integer number may be expressed like a fraction, by writing 1 below it, as a denominator; so 3 is  $\frac{3}{1}$ , or 4 is  $\frac{4}{1}$ , &c.

A fraction denotes division; and its value is equal to the quotient obtained by dividing the numerator by the denominator; so  $\frac{12}{4}$  is equal to 3, and  $\frac{20}{5}$  is equal to 4.

Hence then, if the numerator be less than the denominator, the value of the fraction is less than 1. If the numerator be the same as the denominator, the fraction is just equal to 1. And if the numerator be greater than the denominator, the fraction is greater than 1.

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## REDUCTION OF VULGAR FRACTIONS.

REDUCTION of Vulgar Fractions, is the bringing them out of one form or denomination into another; commonly to prepare them for the operations of Addition, Subtraction, &c. of which there are several cases.

### PROBLEM.

*To find the Greatest Common Measure of Two or more Numbers.*

THE Common Measure of two or more numbers, is that number which will divide them both without remainder; so, 3 is a common measure of 18 and 24; the quotient of the former being 6, and of the latter 8. And the greatest number that will do this, is the greatest common measure: so 6 is the greatest common measure of 18 and 24; the quotient of the former being 3, and of the latter 4, which will not both divide farther.

### RULE.

IF there be two numbers only; divide the greater by the less; then divide the divisor by the remainder; and so on, dividing always the last divisor by the last remainder; till nothing remains; so shall the last divisor of all be the greatest common measure sought.

When there are more than two numbers; find the greatest common measure of two of them, as before; then do the same for that common measure and another of the numbers; and

and so on, through all the numbers; so will the greatest common measure last found be the answer.

If it happen that the common measure thus found is 1; then the numbers are said to be incommensurable, or not having any common measure.

## EXAMPLES.

1. To find the greatest common measure of 1998, 918, and 522.

$$\begin{array}{r}
 918) 1998 (2 \\
 \underline{1836} \\
 162) 918 (5 \quad \text{Hence } 54) \quad 522 (9 \\
 \underline{810} \qquad \qquad \qquad \underline{486} \\
 108) 162 (1 \qquad \qquad \qquad 36) 54 (1 \\
 \underline{108} \qquad \qquad \qquad \underline{36} \\
 54) 108 (2 \qquad \qquad \qquad 18) 36 (2 \\
 \underline{108} \qquad \qquad \qquad \underline{36}
 \end{array}$$

So that 18 is the answer required.

2. What is the greatest common measure of 246 and 372?

Anf. 6.

3. What is the greatest common measure of 336, 720, and 1736?

Anf. 8.

## CASE I.

*To Abbreviate or Reduce Fractions to their Lowest Terms.*

## RULE\*.

DIVIDE the terms of the given fraction by any number that will divide them without a remainder; then divide these quotients

\* That dividing both the terms of the fraction by the same number, whatever it be, will give another fraction equal to the former, is evident. And when these divisions are performed as often as can be done, or when the common divisor is the greatest possible, the terms of the resulting fraction must be the least possible.

Note. 1. Any number ending with an even number, or a cipher, is divisible, or can be divided, by 2.

2. Any number ending with 5, or 0, is divisible by 5.

3. If

quotients again in the same manner; and so on, till it appears that there is no number greater than 1 which will divide them; then the fraction will be in its lowest terms.

*Or,* Divide both the terms of the fraction by their greatest common measure at once, and the quotients will be the terms of the fraction required, of the same value as at first.

### EXAMPLES.

1. Reduce  $\frac{144}{240}$  to its least terms.

$$\frac{144}{240} = \frac{12}{20} = \frac{6}{10} = \frac{3}{5}, \text{ the Answer.}$$

Or thus:

144) 240 (1	Therefore 48 is the greatest common measure; and $48) \frac{144}{240} = \frac{3}{5}$ the Answer, the same as before.
144	
— 96) 144 (1	
96	
— 48) 96 (2	
96	
—	

2. Reduce

3. If the right-hand place of any number be 0, the whole is divisible by 10; if there be two ciphers, it is divisible by 100; if three ciphers, by 1000: and so on; which is only cutting off those ciphers.

4. If the two right-hand figures of any number be divisible by 4, the whole is divisible by 4. And if the three right-hand figures be divisible by 8, the whole is divisible by 8. And so on.

5. If the sum of the digits in any number be divisible by 3, or by 9, the whole is divisible by 3, or by 9.

6. If the right-hand digit be even, and the sum of all the digits be divisible by 6, then the whole will be divisible by 6.

7. A number is divisible by 11, when the sum of the 1st, 3d, 5th, &c. or all the odd places, is equal to the sum of the 2d, 4th, 6th, &c. or of all the even places of digits.

8. If a number cannot be divided by some quantity less than the square of the same, that number is a prime, or cannot be divided by any number whatever.

9. All prime numbers, except 2 and 5, have either 1, 3, 7, or 9, in the place of units; and all other numbers are composite, or can be divided.

10. When

2. Reduce  $\frac{19}{5} \frac{2}{6}$  to its lowest terms. Ans.  $\frac{2}{3}$ .  
 3. Reduce  $\frac{25}{3} \frac{5}{6} \frac{4}{4}$  to its lowest terms. Ans.  $\frac{9}{13}$ .  
 4. Reduce  $\frac{1}{1} \frac{3}{5} \frac{4}{6} \frac{4}{6}$  to its lowest terms. Ans.  $\frac{7}{8}$ .

## CASE II.

*To Reduce a Mixed Number to its Equivalent Improper Fraction.*

## RULE\*.

MULTIPLY the whole number by the denominator of the fraction, and add the numerator to the product; then set that sum above the denominator for the fraction required.

## EXAMPLES.

1. Reduce  $23\frac{2}{5}$  to a fraction.

$$\begin{array}{r} 23 \\ 5 \\ \hline 115 \\ 2 \\ \hline 117 \\ 5 \\ \hline \end{array}$$

$$Or, \quad \frac{(23 \times 5) + 2}{5} = \frac{117}{5}, \text{ the Answer.}$$

2. Reduce  $12\frac{7}{9}$  to a fraction.  
 3. Reduce  $14\frac{7}{15}$  to a fraction.  
 4. Reduce  $183\frac{5}{21}$  to a fraction.

Ans.  $\frac{115}{9}$ .  
 Ans.  $\frac{147}{15}$ .  
 Ans.  $\frac{3548}{21}$ .

10. When numbers, with the sign of addition or subtraction between them, are to be divided by any number, then each of those numbers must be divided by it. Thus  $\frac{10+8-4}{2} = 5+4-2=7$ .

11. But if the numbers have the sign of multiplication between them, only one of them must be divided. Thus,

$$\frac{10 \times 8 \times 3}{6 \times 2} = \frac{10 \times 4 \times 3}{6 \times 1} = \frac{10 \times 4 \times 1}{2 \times 1} = \frac{10 \times 2 \times 1}{1 \times 1} = \frac{20}{1} = 20.$$

\* This is no more than first multiplying a quantity by some number, and then dividing the result back again by the same, which it is evident does not alter the value; for any fraction represents a division of the numerator by the denominator.

## CASE III.

*To Reduce an Improper Fraction to its Equivalent Whole or Mixed Number.*

## RULE \*.

DIVIDE the numerator by the denominator, and the quotient will be the whole or mixed number sought.

## EXAMPLES.

1. Reduce  $\frac{12}{3}$  to its equivalent number.

Here  $\frac{12}{3}$  or  $12 \div 3 = 4$ , the Answer.

2. Reduce  $\frac{15}{7}$  to its equivalent number.

Here  $\frac{15}{7}$  or  $15 \div 7 = 2\frac{1}{7}$ , the Answer.

3. Reduce  $\frac{749}{17}$  to its equivalent number.

Thus, 17) 749 (4 $\frac{1}{17}$

68

—  
69  
68  
—  
1

So that  $\frac{749}{17} = 44\frac{1}{17}$ , the Answer.

4. Reduce  $\frac{56}{7}$  to its equivalent number.

Anf. 8.

5. Reduce  $\frac{1362}{25}$  to its equivalent number.

Anf.  $54\frac{12}{25}$ .

6. Reduce  $\frac{2918}{17}$  to its equivalent number.

Anf.  $171\frac{1}{17}$ .

## CASE IV.

*To Reduce a Whole Number to an Equivalent Fraction, having a Given Denominator.*

## RULE †.

MULTIPLY the whole number by the given denominator; then set the product over the said denominator, and it will form the fraction required.

\* This Rule is evidently the reverse of the former; and the reason of it is manifest from the nature of Common Division.

† Multiplication and Division being here equally used, the result must be the same as the quantity first proposed.

## EXAMPLES.

1. Reduce  $\frac{9}{7}$  to a fraction whose denominator shall be 7.

Here  $9 \times 7 = 63$ : then  $\frac{63}{7}$  is the Answer;

For  $\frac{63}{7} = 63 \div 7 = 9$ , the Proof.

2. Reduce  $\frac{13}{7}$  to a fraction whose denominator shall be 12.

Ans.  $\frac{156}{144}$ .

3. Reduce  $\frac{27}{7}$  to a fraction whose denominator shall be 11.

Ans.  $\frac{297}{143}$ .

## CASE V.

*To Reduce a Compound Fraction to an Equivalent Simple One.*

## RULE\*.

MULTIPLY all the numerators together for a numerator, and all the denominators together for a denominator, and they will form the simple fraction sought.

When part of the compound fraction is a whole or mixed number, it must first be reduced to a fraction by one of the former cases.

And, when it can be done, any two terms of the fraction may be divided by the same number, and the quotients used instead of them. Or when there are terms that are common, they may be omitted.

## EXAMPLES.

1. Reduce  $\frac{1}{2}$  of  $\frac{2}{3}$  of  $\frac{3}{4}$  to a simple fraction.

Here  $\frac{1 \times 2 \times 3}{2 \times 3 \times 4} = \frac{6}{24} = \frac{1}{4}$ , the Answer.

Or,  $\frac{1 \times 2 \times 3}{2 \times 3 \times 4} = \frac{1}{4}$ , by omitting the 2's and 3's.

\* The truth of this Rule may be shewn as follows: Let the compound fraction be  $\frac{2}{3}$  of  $\frac{5}{7}$ . Now  $\frac{2}{3}$  of  $\frac{5}{7}$  is  $\frac{5}{7} \div 3$ , which is  $\frac{5}{21}$ ; consequently  $\frac{2}{3}$  of  $\frac{5}{7}$  will be  $\frac{5}{21} \times 2$  or  $\frac{10}{21}$ ; that is, the numerators are multiplied together, and also the denominators, as in the Rule. When the compound fraction consists of more than two single ones; having first reduced two of them as above, then the resulting fraction and a third will be the same as a compound fraction of two parts; and so on to the last of all.

2. Reduce

2. Reduce  $\frac{2}{3}$  of  $\frac{10}{11}$  to a simple fraction.

Here  $\frac{2 \times 3 \times 10}{3 \times 5 \times 11} = \frac{60}{165} = \frac{12}{33} = \frac{4}{11}$ , the Answer.

Or,  $\frac{2 \times 3 \times 10}{3 \times 5 \times 11} = \frac{4}{11}$ , the same as before.

- |  |                         |
|--|-------------------------|
| 3. Reduce $\frac{3}{7}$ of $\frac{4}{5}$ to a simple fraction.                       | Ansl. $\frac{12}{35}$ . |
| 4. Reduce $\frac{2}{3}$ of $\frac{3}{4}$ of $\frac{5}{6}$ to a simple fraction.      | Ansl. $\frac{1}{4}$ .   |
| 5. Reduce $\frac{2}{5}$ of $\frac{5}{8}$ of $3\frac{1}{2}$ to a simple fraction.     | Ansl. $\frac{7}{8}$ .   |
| 6. Reduce $\frac{2}{7}$ of $\frac{5}{8}$ of $\frac{7}{2}$ of 4 to a simple fraction. | Ansl. $\frac{5}{2}$ .   |
| 7. Reduce $2\frac{2}{3}$ of $\frac{5}{6}$ to a fraction.                             | Ansl. $\frac{7}{3}$ .   |

#### CASE VI.

*To Reduce Fractions of Different Denominators to Equivalent Fractions having a Common Denominator.*

#### RULE\*.

MULTIPLY each numerator by all the denominators except its own, for the new numerators; and multiply all the denominators together for a common denominator.

Note, It is evident, that in this and several other operations, when any of the proposed quantities are integers, or mixed numbers, or compound fractions, they must be reduced, by their proper Rules, to the form of simple fractions.

#### EXAMPLES.

1. Reduce  $\frac{1}{2}$ ,  $\frac{2}{3}$ , and  $\frac{3}{4}$ , to a common denominator.

$1 \times 3 \times 4 = 12$  the new numerator for  $\frac{1}{2}$ .

$2 \times 2 \times 4 = 16$  ditto for  $\frac{2}{3}$ .

$3 \times 2 \times 3 = 18$  ditto for  $\frac{3}{4}$ .

$2 \times 3 \times 4 = 24$  the common denominator.

Therefore the equivalent fractions are  $\frac{1}{2}, \frac{2}{3}, \frac{3}{4}$ , and  $\frac{1}{2}$ .

Or the whole operation of multiplying may be very well performed mentally, only setting down the results and

\* This is evidently no more than multiplying each numerator and its denominator by the same quantity, and consequently the value of the fraction is not altered.

given fractions thus:  $\frac{1}{2}$ ,  $\frac{2}{3}$ ,  $\frac{3}{4} = \frac{12}{24}$ ,  $\frac{16}{24}$ ,  $\frac{18}{24} = \frac{6}{12}$ ,  $\frac{9}{12}$ ,  $\frac{9}{2}$ , by abbreviation

2. Reduce  $\frac{2}{7}$  and  $\frac{5}{9}$  to fractions of a common denominator.

Ansf.  $\frac{18}{63}$ ,  $\frac{35}{63}$ .

3. Reduce  $\frac{2}{3}$ ,  $\frac{3}{5}$ , and  $\frac{3}{4}$  to a common denominator.

Anf.  $\frac{40}{60}$ ,  $\frac{36}{60}$ ,  $\frac{45}{60}$ .

4. Reduce  $\frac{5}{6}$ ,  $2\frac{1}{5}$ , and 4 to a common denominator.

Anf.  $\frac{25}{30}$ ,  $\frac{73}{30}$ ,  $\frac{120}{30}$ .

*Note 1.* When the denominators of two given fractions have a common measure, let them be divided by it; then multiply the terms of each given fraction by the quotient arising from the other's denominator.

2. When the less denominator of two fractions exactly divides the greater, multiply the terms of that which hath the less denominator by the quotient.

3. When more than two fractions are proposed, it is sometime convenient, first to reduce two of them to a common denominator; then these and a third; and so on till they be all reduced to their least common denominator.

### CASE VII.

*To find the Value of a Fraction in Parts of the Integer.*

#### RULE.

MULTIPLY the integer by the numerator, and divide the product by the denominator, by Compound Multiplication and Division, if the integer be a compound quantity.

Or, if it be a single integer, multiply the numerator by the parts in the next inferior denomination, and divide the product by the denominator. Then, if any thing remains, multiply it by the parts in the next inferior denomination, and divide by the denominator as before; and so on as far as necessary; so shall the quotients, placed in order, be the value of the fraction required\*.

\* The numerator of a fraction being considered as a remainder, in Division, and the denominator as the divisor, this rule is of the same nature as Compound Division, or the valuation of remainders in the Rule of Three, before explained.

## EXAMPLES.

1. What is the  $\frac{4}{5}$  of 2l 6s?

By the former part of the Rule,

$$\begin{array}{r} 2l \ 6s \\ \times \ 4 \\ \hline \end{array}$$

$$\begin{array}{r} 5) \ 9 \ 4 \\ \hline \end{array}$$

Ansf.  $1l \ 16s \ 9d \ 2\frac{2}{5}q.$

2. What is the value of  $\frac{2}{3}$  of 1l?

By the 2d part of the Rule,

$$\begin{array}{r} 2 \\ \times 20 \\ \hline \end{array}$$

$$\begin{array}{r} 3) \ 40 \ (13s \ 4d \ \text{Ans}. \\ \hline \end{array}$$

$$\begin{array}{r} 1 \\ \times 12 \\ \hline \end{array}$$

$$\begin{array}{r} 3) \ 12 \ (4d \\ \hline \end{array}$$

3. Find the value or  $\frac{3}{8}$  of a pound sterl. Ansf. 7s 6d.

4. What is the value of  $\frac{2}{5}$  of a guinea? Ansf. 4s 8d.

5. What is the value of  $\frac{3}{4}$  of a half crown? Ansf. 1s  $10\frac{1}{2}d$ .

6. What is the value of  $\frac{2}{3}$  of 4s 10d? Ansf. 1s  $11\frac{1}{5}d$ .

7. What is the value of  $\frac{3}{5}$  lb troy? Ansf. 7oz 4dwts.

8. What is the value of  $\frac{5}{16}$  of a cwt? Ansf. 1qr 7lb.

9. What is the value of  $\frac{5}{8}$  of an acre? Ansf. 2 ro 20 po.

10. What is the value of  $\frac{3}{10}$  of a day? Ansf. 7hrs 12min.

## CASE VIII.

*To Reduce a Fraction from one Denomination to another,*

## RULE\*.

CONSIDER how many of the less denomination make one of the greater; then multiply the numerator by that number, if the reduction be to a less name, or multiply the denominator, if to a greater.

## EXAMPLES.

1. Reduce  $\frac{2}{5}$  of a pound to the fraction of a penny.

$$\frac{2}{5} \times \frac{20}{1} \times \frac{12}{1} = \frac{480}{5} = \frac{160}{1}, \text{ the Answer.}$$

\* This is the same as the Rule of Reduction in whole numbers from one denomination to another.

2. Reduce  $\frac{5}{6}$  of a penny to the fraction of a pound.  
 $\frac{5}{6} \times \frac{1}{12} \times \frac{1}{20} = \frac{5}{1440} = \frac{1}{288}$ , the Answer.
3. Reduce  $\frac{2}{5}l$  to the fraction of a penny. Anf.  $\frac{3}{4}d$ .
4. Reduce  $\frac{2}{3}q$  to the fraction of a pound. Anf.  $\frac{1}{4\frac{1}{3}}$ .
5. Reduce  $\frac{2}{7}$ cwt to the fraction of a lb. Anf.  $\frac{3}{7}$ .
6. Reduce  $\frac{4}{5}$ dwt to the fraction of a lb troy. Anf.  $\frac{1}{300}$ .
7. Reduce  $\frac{5}{8}$ crown to the fract. of a guinea. Anf.  $\frac{2\frac{5}{8}}{16\frac{1}{2}}$ .
8. Reduce  $\frac{5}{6}$ half-crown to the fract. of a shilling. Anf.  $\frac{2\frac{5}{6}}{12}$ .
9. Reduce  $2s\ 6d$  to the fraction of a £. Anf.  $\frac{1}{4}$ .
10. Reduce  $17s\ 7d\ 3\frac{3}{5}q$  to the fraction of a £.
- 

## ADDITION OF VULGAR FRACTIONS.

## RULE.

If the fractions have a common denominator; add all the numerators together, then place the sum over the common denominator, and that will be the sum of the fractions required.

\* If the proposed fractions have not a common denominator, they must be reduced to one. Also compound fractions must be reduced to simple ones; and mixed numbers to improper fractions: also fractions of different denominations to those of the same denomination. Then add the numerators as before.

---

\* Before fractions are reduced to a common denominator, they are quite dissimilar, as much as shillings and pence are, and therefore cannot be incorporated with one another, any more than these can. But when they are reduced to a common denominator, and made parts of the same thing, their sum, or difference, may then be as properly expressed by the sum or difference of the numerators, as the sum or difference of any two quantities whatever, by the sum or difference of their individuals. Whence the reason of the Rule is manifest, both for Addition and Subtraction.

When several fractions are to be collected, it is commonly best first to add two of them together that most easily reduce to a common denominator; then add their sum and a third, and so on.

## EXAMPLES.

1. To add  $\frac{2}{5}$  and  $\frac{4}{5}$  together.

Here  $\frac{2}{5} + \frac{4}{5} = \frac{7}{5} = 1\frac{2}{5}$ , the Answer.

2. To add  $\frac{3}{5}$  and  $\frac{5}{6}$  together.

$\frac{3}{5} + \frac{5}{6} = \frac{18}{30} + \frac{25}{30} = \frac{43}{30} = 1\frac{13}{30}$ , the Answer.

3. To add  $\frac{5}{8}$  and  $7\frac{1}{2}$  and  $\frac{1}{3}$  of  $\frac{3}{4}$  together.

$\frac{5}{8} + 7\frac{1}{2} + \frac{1}{3} \text{ of } \frac{3}{4} = \frac{5}{8} + \frac{15}{2} + \frac{1}{4} = \frac{5}{8} + \frac{60}{8} + \frac{2}{8} = \frac{67}{8} = 8\frac{3}{8}$ .

4. To add  $\frac{3}{7}$  and  $\frac{6}{7}$  together.

Anf.  $1\frac{2}{7}$ .

5. To add  $\frac{4}{5}$  and  $\frac{5}{9}$  together.

Anf.  $1\frac{1}{3}\frac{1}{9}$ .

6. Add  $\frac{2}{7}$  and  $\frac{5}{14}$  together.

Anf.  $\frac{9}{14}$ .

7. What is the sum of  $\frac{2}{3}$  and  $\frac{3}{5}$  and  $\frac{5}{7}$ ?

Anf.  $1\frac{10}{21}$ .

8. What is the sum  $\frac{5}{9}$  and  $\frac{3}{5}$  and  $2\frac{1}{6}$ ?

Anf.  $3\frac{2}{9}$ .

9. What is the sum of  $\frac{3}{5}$  and  $\frac{4}{5}$  of  $\frac{1}{3}$ ; and  $9\frac{3}{25}$ ? Anf.  $10\frac{6}{25}$ .

10. What is the sum of  $\frac{2}{3}$  of a pound and  $\frac{5}{9}$  of a shilling?

Anf.  $1\frac{2}{3}s$  or  $13s 10d 2\frac{2}{3}q$ .

11. What is the sum of  $\frac{3}{5}$  of a shilling and  $\frac{4}{15}$  of a penny?

Anf.  $\frac{112}{15}d$  or  $7d 1\frac{3}{5}q$ .

12. What is the sum of  $\frac{1}{7}$  of a pound, and  $\frac{2}{9}$  of a shilling, and  $\frac{5}{12}$  of a penny?

Anf.  $3\frac{13}{18}s$  or  $3s 1d 1\frac{1}{2}q$ .

13. To sum  $7\frac{3}{5}$  of  $\frac{4}{7} + \frac{3}{5}$  of  $\frac{4}{7}$  of  $7 + 5\frac{3}{7} + \frac{9}{14}$ . Anf.  $16\frac{263}{1435}$ .

## SUBTRACTION OF VULGAR FRACTIONS.

## RULE.

PREPARE the fractions the same as for Addition, when necessary; then subtract the one numerator from the other, and set the remainder over the common denominator, for the difference of the fractions sought.

## EXAMPLES.

1. To find the difference between  $\frac{5}{6}$  and  $\frac{1}{6}$ .

Here  $\frac{5}{6} - \frac{1}{6} = \frac{4}{6} = \frac{2}{3}$ , the Answer.

2. To find the difference between  $\frac{3}{4}$  and  $\frac{5}{7}$ .

$\frac{3}{4} - \frac{5}{7} = \frac{21}{28} - \frac{20}{28} = \frac{1}{28}$ , the Answer.

3. What

3. What is the difference between  $\frac{5}{12}$  and  $\frac{7}{12}$ ? Ans.  $\frac{1}{6}$ .  
 4. What is the difference between  $\frac{3}{5}$  and  $\frac{4}{30}$ ? Ans.  $\frac{5}{9}$ .  
 5. What is the difference between  $\frac{5}{12}$  and  $\frac{7}{15}$ ? Ans.  $\frac{1}{30}$ .  
 6. What is the diff. between  $5\frac{3}{5}$  and  $\frac{2}{7}$  of  $4\frac{1}{6}$ ? Ans.  $4\frac{3}{68}$ .  
 7. What is the difference between  $\frac{5}{9}$  of a pound, and  $\frac{2}{3}$  of  $\frac{3}{4}$  of a shilling? Ans.  $10s\ 7d\ 1\frac{1}{3}g.$   
 8. What is the difference between  $\frac{2}{7}$  of  $5\frac{1}{8}$  of a pound, and  $\frac{3}{5}$  of a shilling? Ans.  $3\frac{217}{128}l$  or  $1l\ 8s\ 11\frac{3}{5}d.$
- 

## MULTIPLICATION OF VULGAR FRACTIONS.

## RULE \*.

REDUCE mixed numbers, if there be any, to equivalent fractions; then multiply all the numerators together for a numerator, and all the denominators together for a denominator, which will give the product required.

## EXAMPLES.

1. Required the product of  $\frac{3}{4}$  and  $\frac{2}{9}$ .

Here  $\frac{3}{4} \times \frac{2}{9} = \frac{6}{36} = \frac{1}{6}$ , the Answer.

Or  $\frac{3}{4} \times \frac{2}{9} = \frac{1}{2} \times \frac{1}{3} = \frac{1}{6}$ .

2. Required the continued product of  $\frac{2}{3}$ ,  $3\frac{1}{4}$ , 5, and  $\frac{3}{4}$  of  $\frac{1}{2}$ .

Here  $\frac{2}{3} \times \frac{13}{4} \times \frac{5}{1} \times \frac{8}{2} \times \frac{3}{5} = \frac{13 \times 3}{4 \times 2} = \frac{39}{8} = 4\frac{7}{8}$ , Ans.

3. Required the product of  $\frac{2}{7}$  and  $\frac{5}{3}$ .

Ans.  $\frac{5}{21}$ .

4. Required the product of  $\frac{4}{15}$  and  $\frac{5}{24}$ .

Ans.  $\frac{1}{18}$ .

5. Required the product of  $\frac{3}{7}$ ,  $\frac{4}{9}$ , and  $\frac{14}{15}$ .

Ans.  $\frac{9}{45}$ .

\* Multiplication of any thing by a fraction implies the taking some part or parts of the thing; it may therefore be truly expressed by a compound fraction; which is resolved by multiplying together the numerators and the denominators.

Note, A fraction is best multiplied by an integer, by dividing the denominator by it; but if it will not exactly divide, then multiply the numerator by it.

6. Required

6. Required the product of  $\frac{1}{2}$ ,  $\frac{2}{3}$ , and 3. Ans. 1.
7. Required the product of  $\frac{2}{9}$ ,  $\frac{3}{5}$ , and  $4\frac{5}{4}$ . Ans.  $2\frac{1}{3}\frac{1}{8}$ .
8. Required the product of  $\frac{5}{6}$ , and  $\frac{2}{3}$  of  $\frac{6}{7}$ . Ans.  $\frac{10}{21}$ .
9. Required the product of 6, and  $\frac{2}{3}$  of 5. Ans. 20.
10. Required the product of  $\frac{2}{9}$  of  $\frac{3}{5}$ , and  $\frac{5}{8}$  of  $3\frac{2}{7}$ . Ans.  $\frac{23}{84}$ .
11. Required the product of  $3\frac{2}{7}$ , and  $4\frac{1}{3}\frac{4}{5}$ . Ans.  $14\frac{12}{21}\frac{4}{5}$ .
12. Required the product of 5,  $\frac{2}{3}$ ,  $\frac{2}{7}$  of  $\frac{7}{5}$ , and  $4\frac{1}{6}$ . Ans.  $2\frac{3}{14}$ .
- 

## DIVISION OF VULGAR FRACTIONS.

### RULE \*.

PREPARE the fractions as before in Multiplication; then divide the numerator by the numerator, and the denominator by the denominator, if they will exactly divide; but if not, then invert the terms of the divisor, and multiply the dividend by it, as in Multiplication.

### EXAMPLES.

1. Divide  $\frac{2}{9}$  by  $\frac{5}{3}$ .

Here  $\frac{2}{9} \div \frac{5}{3} = \frac{2}{9} \times \frac{3}{5} = 1\frac{2}{3}$ , by the first method.

2. Divide  $\frac{5}{9}$  by  $\frac{2}{5}$ .

Here  $\frac{5}{9} \div \frac{2}{5} = \frac{5}{9} \times \frac{5}{2} = \frac{5}{9} \times \frac{5}{2} = \frac{25}{18} = 4\frac{1}{18}$ .

3. It is required to divide  $\frac{1}{2}\frac{6}{5}$  by  $\frac{4}{5}$ .

Ans.  $\frac{4}{5}$ .

4. It is required to divide  $\frac{7}{16}$  by  $\frac{3}{4}$ .

Ans.  $\frac{7}{12}$ .

5. It is required to divide  $\frac{1}{9}\frac{4}{5}$  by  $\frac{7}{6}$ .

Ans.  $1\frac{1}{3}$ .

6. It is required to divide  $\frac{5}{6}$  by  $\frac{1}{7}\frac{5}{6}$ .

Ans.  $\frac{7}{18}$ .

7. It is required to divide  $\frac{1}{3}\frac{2}{5}$ , by  $\frac{3}{5}$ .

Ans.  $\frac{4}{7}$ .

8. It is required to divide  $\frac{2}{7}$  by  $\frac{3}{5}$ .

Ans.  $\frac{10}{21}$ .

\* Division being the reverse of Multiplication, the reason of the Rule is evident.

Note, A fraction is best divided by an integer, by dividing the numerator by it; but if it will not exactly divide, then multiply the denominator by it.

9. It is required to divide  $\frac{9}{16}$  by 3. Ans.  $\frac{3}{16}$ .  
 10. It is required to divide  $\frac{3}{5}$  by 2. Ans.  $\frac{3}{10}$ .  
 11. It is required to divide  $7\frac{1}{3}$  by  $9\frac{1}{2}$ . Ans.  $\frac{2}{3}\frac{2}{3}$ .  
 12. It is required to divide  $\frac{2}{3}$  of  $\frac{1}{3}$  by  $\frac{5}{7}$  of  $7\frac{2}{3}$ . Ans.  $\frac{7}{15}$ .
- 

## RULE OF THREE IN VULGAR FRACTIONS.

## RULE.

MAKE the necessary preparations as before directed; then multiply continually together, the second and third terms, and the first with its parts inverted as in Division, for the answer\*.

## EXAMPLES.

1. If  $\frac{3}{8}$  of a yard of velvet cost  $\frac{2}{3}$  of a pound sterling; what will  $\frac{5}{16}$  of a yard cost?  
 $\frac{3}{8} : \frac{2}{5} :: \frac{5}{16} : \frac{8}{3} \times \frac{2}{3} \times \frac{5}{16} = \frac{1}{3}l = 6s 8d$ , Answer.
2. What will  $3\frac{3}{8}$  oz of silver cost, at 6s 4d an ounce?  
 Ans. 1l 1s  $4\frac{1}{2}$ d.
3. If  $\frac{3}{5}$  of a ship be worth 273l 2s 6d; what are  $\frac{5}{32}$  of her worth?  
 Ans. 227l 12s 1d.
4. What is the purchase of 1230l bank-stock, at  $108\frac{5}{8}$  per cent.? Ans. 1336l 1s 9d.
5. What is the interest of 273l 15s for a year, at  $3\frac{1}{4}$  per cent.? Ans. 8l 17s  $11\frac{1}{4}$ d.
6. If  $\frac{1}{2}$  of a ship be worth 73l 1s 3d; what part of her is worth 250l 10s?  
 Ans.  $\frac{3}{7}$ .
7. What length must be cut off a board that is  $7\frac{1}{4}$  inches broad, to contain a square foot, or as much as another piece of 12 inches long and 12 broad?  
 Ans.  $18\frac{1}{3}\frac{8}{1}$  inches.
8. What quantity of shalloon that is  $\frac{2}{3}$  of a yard wide, will line  $9\frac{1}{2}$  yards of cloth that is  $2\frac{1}{2}$  yards wide?  
 Ans.  $31\frac{2}{3}$  yds.
- 

\* This is only multiplying the 2d and 3d terms together, and dividing the product by the first, as in the Rule of Three in whole numbers.

9. If the penny loaf weigh  $6\frac{9}{10}$  oz when the price of wheat is 5s the bushel; what ought it to weigh when the wheat is at 8s 6d the bushel? Anf.  $4\frac{1}{7}$  oz.

10. How much in length, of a piece of land that is  $11\frac{1}{2}$  poles broad, will make an acre of land, or as much as 40 poles in length and 4 in breadth? Anf.  $13\frac{6\frac{1}{3}}{7}$  poles.

11. If a courier perform a certain journey in  $35\frac{1}{2}$  days, travelling  $13\frac{5}{8}$  hours a day; how long would he be in performing the same, travelling only  $11\frac{9}{10}$  hours a day?

Anf.  $40\frac{6\frac{1}{5}}{9\frac{1}{2}}$  days.

12. A regiment of soldiers, consisting of 976 men, are to be new cloathed; each coat to contain  $2\frac{1}{2}$  yards of cloth that is  $1\frac{5}{8}$  yard wide, and lined with shalloon  $\frac{7}{8}$  yard wide: how many yards of shalloon will line them?

Anf. 4531yds 1qt  $2\frac{6}{7}$  nails.

## DECIMAL FRACTIONS.

A DECIMAL FRACTION is that which has for its denominator an unit (1) with as many ciphers annexed as the numerator has places; and it is usually expressed by setting down the numerator only, with a point before it, on the left-hand. Thus,  $\frac{5}{10}$  is .5, and  $\frac{25}{100}$  is .25, and  $\frac{75}{1000}$  is .075, and  $\frac{124}{10000}$  is .00124; where ciphers are prefixed to make up as many places as are ciphers in the denominator, when there is a deficiency of figures.

A mixed number is made up of a whole number with some decimal fraction, the one being separated from the other by a point. Thus, 3.25 is the same as  $3\frac{25}{100}$ , or  $3\frac{25}{100}$ .

Ciphers on the right hand of decimals make no alteration in their value; for .5, or .50, or .500, are decimals having all the same value, being each  $=\frac{5}{10}$ , or  $\frac{1}{2}$ . But if they are placed on the left-hand, they decrease the value in a ten-fold proportion: Thus, .5 is  $\frac{5}{10}$ , or 5 tenths; but .05 is only  $\frac{5}{100}$ , or 5 hundredths, and .005 is but  $\frac{5}{1000}$ , or 5 thousandths.

The 1st place of decimals, counted from the left-hand towards the right, is called the place of primes, or 10ths; the 2d is the place of seconds, or 100ths; the 3d is the place of thirds, or 1000ths; and so on. For, in decimals, as well as in whole numbers, the values of the places increase towards the left-hand, and decrease towards the right, both in the same

same tenfold proportion; as in the following Scale or Table of Notation:

3 millions	hundred thousands													
3	3	3	ten thousands											
			3	thousands										
				3	hundreds									
					3	tens								
						3	units							
							3 · 3	tenth parts						
								3	hundredth parts					
									3	thousandth parts				
										ten thousandth parts				
											hundred thousandth parts			
												millionth parts		
												3		

## ADDITION OF DECIMALS.

## RULE.

SET the numbers under each other according to the value of their places, like as in whole numbers; in which state the decimal separating points will stand all exactly under each other. Then, beginning at the right hand, add up all the columns of numbers as in integers; and point off as many places, for decimals, as are in the greatest number of decimal places in any of the lines that are added; or place the point directly below all the other points.

## EXAMPLES.

1. To add together 29·0146, and 3146·5, and 2109, and 62417, and 14·16.

$$\begin{array}{r}
 29\cdot0146 \\
 3146\cdot5 \\
 2109\cdot \\
 \cdot62417 \\
 14\cdot16 \\
 \hline
 \end{array}$$

5299·29877 the Sum.

- Ex. 2. To find the sum of 376·25 + 86·125 + 637·4725 + 6·5 + 41·02 + 358·865. Anf. 1506 2325.  
 3. Required the sum of 3·5 + 47·25 + 2·0073 + 927·01 + 1·5. Anf. 981 2673.  
 4. Required the sum of 276 + 54·321 + 112 + 0·65 + 12·5 + 0·0463. Anf. 455·5173.

## SUBTRACTION OF DECIMALS.

## RULE.

PLACE the numbers under each other according to the value of their places, as in the last Rule. Then, beginning at the right hand, subtract as in whole numbers, and point off the decimals as in Addition.

## EXAMPLES.

1. To find the difference between 91·73 and 2·138.

$$\begin{array}{r} 91\cdot73 \\ - 2\cdot138 \\ \hline \text{Ans. } 89\cdot592 \text{ the Difference.} \end{array}$$

2. Find the diff. between 1·9185 and 2·73. Ans. 0·8115.

3. To subtract 4·90142 from 214·81. Ans. 209·90858.

4. Find the diff. between 2714 and '916. Ans. 2713·084.

## MULTIPLICATION OF DECIMALS.

## RULE\*.

PLACE the factors, and multiply them together the same as if they were whole numbers.—Then point off in the product just as many places of decimals as there are decimals in both the factors. But if there be not so many figures in the product, then supply the defect by prefixing ciphers.

\* The Rule will be evident from this example:—Let it be required to multiply ·12 by ·361; these numbers are equivalent to  $\frac{12}{100}$  and  $\frac{361}{1000}$ ; the product of which is  $\frac{4332}{100000} = \cdot04332$ , by the nature of Notation, which consists of as many places as there are ciphers, that is, of as many places as there are in both numbers. And in like manner for any other numbers.

## EXAMPLES.

$$\begin{array}{r}
 \text{1. Multiply } .321096 \\
 \text{by } .2465 \\
 \hline
 1605480 \\
 1926576 \\
 1284384 \\
 642192 \\
 \hline
 \end{array}$$

Anf. .0791501640 the Product.

- |                                |                    |
|--------------------------------|--------------------|
| 2. Multiply 79·347 by 23·15.   | Anf. 1836·88805.   |
| 3. Multiply .63478 by .8204.   | Anf. .520773512.   |
| 4. Multiply .385746 by .00464. | Anf. .00178986144. |

## CONTRACTION I.

*To multiply Decimals by 1 with any number of Ciphers, as by 10, or 100, or 1000, &c.*

THIS is done by only removing the decimal point so many places farther to the right-hand as there are ciphers in the multiplier; and subjoining ciphers if need be.

## EXAMPLES.

1. The product of 51·3 and 1000 is 51300.
2. The product of 2·714 and 100 is
3. The product of .916 and 1000 is
4. The product of 21·31 and 10000 is

## CONTRACTION II.

*To Contract the Operation, so as to retain only as many Decimals in the Product as may be thought Necessary, when the Product would naturally contain several more Places.*

SET the units' place of the multiplier under that figure of the multiplicand whose place is the same as is to be retained for the last in the product; and dispose of the rest of the figures in the inverted or contrary order to what they are usually placed in.—Then, in multiplying, reject all the figures that are more to the right than each multiplying figure, and set down the products, so that their right-hand figures may fall

fall in a column straight below each other; but observing to increase the first figure of every line with what would arise from the figures omitted, in this manner, namely 1 from 5 to 14, 2 from 15 to 24, 3 from 25 to 34, &c.; and the sum of all the lines will be the product as required, commonly to the nearest unit in the last figure.

## EXAMPLES.

1. To multiply 27·14986 by 92 41035, so as to retain only four places of decimals in the product.

*Contracted Way.*

$$\begin{array}{r} 27\cdot14986 \\ \times 9241035 \\ \hline \end{array}$$

$$\begin{array}{r} 24434874 \\ 542997 \\ 108599 \\ 2715 \\ 81 \\ 14 \\ \hline 2508\cdot9280 \end{array}$$

*Common Way.*

$$\begin{array}{r} 27\cdot14986 \\ \times 9241035 \\ \hline \end{array}$$

$$\begin{array}{r} 13\mid 574930 \\ 81\mid 44958 \\ 2714\mid 986 \\ 108599\mid 44 \\ 542997\mid 2 \\ 2443\mid 4874 \\ \hline 2508\mid 9280\mid 650510 \end{array}$$

2. Multiply 480·14936 by 2 72416, retaining only four decimals in the product.

3. Multiply 2490·3648 by ·573286, retaining only five decimals in the product.

4. Multiply 325·701428 by ·7218393, retaining only three decimals in the product.

## DIVISION OF DECIMALS.

## RULE.

DIVIDE as in whole numbers; and point off in the quotient as many places for decimals, as the decimal places in the dividend exceed those in the divisor \*.

\* The reason of this Rule is evident; for since the divisor multiplied by the quotient gives the dividend, therefore the number of decimal places in the dividend is equal to those in the divisor and quotient, taken together, by the nature of Multiplication; and consequently the quotient itself must contain as many as the dividend exceeds the divisor.

Another way to know the place for the decimal point is this: The first figure of the quotient must be made to occupy the same place, of integers or decimals, as doth that figure of the dividend which stands over the unit's figure of the first product.

When the places of the quotient are not so many as the Rule requires, the defect is to be supplied by prefixing ciphers.

When there happens to be a remainder after the division; or when the decimal places in the divisor are more than those in the dividend; then ciphers may be annexed to the dividend, and the quotient carried on as far as required.

## EXAMPLES.

1.	2.
$179) \cdot 48624097$	$\cdot 00271643$
1282	2655)
294	27·00000 (100·55865
1150	15000
769	15750
537	23250
000	17700
—	15900
	24750

3. Divide 234·70525 by 64·25.

Anf. 3·653.

4. Divide 14 by ·7854.

Anf. 17·825.

5. Divide 2175·68 by 100.

Anf. 21·7568.

6. Divide 8727587 by ·162.

Anf. 5·38739.

## CONTRACTION I.

WHEN the divisor is an integer, with any number of ciphers annexed; cut off those ciphers, and remove the decimal point in the dividend as many places farther to the left as there are ciphers cut off, prefixing ciphers if need be; then proceed as before \*.

\* This is no more than dividing both divisor and dividend by the same number, either 10, or 100, or 1000, &c. according to the number of ciphers cut off; which, leaving them in the same proportion, does not affect the quotient. And, in the same way, the decimal point may be moved the same number of places in both the divisor and dividend, either to the right or left, whether they have ciphers or not.

## EXAMPLES.

1. Divide 45·5 by 2100.

$$\begin{array}{r} 21 \cdot 00 ) \ 455 \ (\ 0216, \text{ &c.} \\ 35 \\ 140 \\ 14 \end{array}$$


---

2. Divide 41020 by 32000.

3. Divide 953 by 21600.

4. Divide 61 by 79000.

## CONTRACTION II.

HENCE, if the divisor be 1 with ciphers, as 10, or 100, or 1000, &c. : then the quotient will be found by merely moving the decimal point in the dividend so many places farther to the left as the divisor has ciphers ; prefixing ciphers if need be.

## EXAMPLES.

$$\text{So, } 217 \cdot 3 \div 100 = 2 \cdot 173.$$

$$\text{And } 419 \div 10 =$$

$$\text{And } 5 \cdot 16 \div 100 = .$$

$$\text{And } 21 \div 1000 =$$

## CONTRACTION III.

WHEN there are many figures in the divisor ; or when only a certain number of decimals are necessary to be retained in the quotient ; then take only as many figures of the divisor as will be equal to the number of figures, both integers and decimals, to be in the quotient, and find how many times they may be contained in the first figures of the dividend, as usual.

Let each remainder be a new dividend ; and for every such dividend, leave out one figure more on the right-hand side of the divisor ; remembering to carry for the increase of the figures cut off, as in the 2d contraction in Multiplication.

*Note.* When there are not so many figures in the divisor as are required to be in the quotient, begin the operation with all the figures, and continue it as usual till the number of figures in the divisor be equal to those remaining to be found in the quotient, after which begin the contraction.

## EXAMPLES.

1. Divide 2508·92806 by 92·41035, so as to have only four decimals in the quotient, in which case the quotient will contain six figures.

<i>Contracted.</i>	<i>Common way.</i>
92·4103,5)2508·928,06(27·1498	92·4103,5)2508·928,06(27·1498
660721	66072106
13849	13848610
4608	46075750
912	91116100
80	79467830
6	5539570

2. Divide 4109·2351 by 230·409, so that the quotient may contain only four decimals. Ans. 17·8345.

3. Divide 37·10438 by 5713·96, that the quotient may contain only five decimals. Ans. ·00649.

4. Divide 913·08 by 2137·2, that the quotient may contain only three decimals.

## REDUCTION OF DECIMALS.

### CASE I.

*To reduce a Vulgar Fraction to its equivalent Decimal.*

#### RULE.

Divide the numerator by the denominator as in Division of Decimals, annexing ciphers to the numerator as far as necessary; so shall the quotient be the decimal required.

#### EXAMPLES.

1. Reduce  $\frac{7}{24}$  to a decimal.

$$\begin{array}{r} 24 = 4 \times 6. \text{ Then } 4) 7. \\ 6) 1.750000. \\ \hline \end{array}$$

·291666, &c.

2. Reduce  $\frac{1}{4}$ , and  $\frac{1}{2}$ , and  $\frac{3}{4}$ , to decimals.

Ans. ·25, and ·5, and ·75,

3. Reduce  $\frac{3}{8}$  to a decimal.

Ans. ·375.

4. Reduce  $\frac{1}{25}$  to a decimal.

Ans. ·04.

5. Reduce  $\frac{3}{125}$  to a decimal.

Ans. ·015625.

6. Reduce  $\frac{275}{3842}$  to a decimal.

Ans. ·071577, &c.

CASE II.

*To find the Value of a Decimal in terms of the Inferior Denominations.*

## RULE.

MULTIPLY the decimal by the number of parts in the next lower denomination; and cut off as many places for a remainder to the right-hand, as there are places in the given decimal.

Multiply that remainder by the parts in the next lower denomination again, cutting off for another remainder as before.

Proceed in the same manner through all the parts of the integer; then the several denominations separated on the left-hand, will make up the answer.

Note, This operation is the same as Reduction Descending in whole numbers.

## EXAMPLES.

1. Required to find the value of .775 pounds sterling.

$$\begin{array}{r}
 \cdot 775 \\
 20 \\
 \hline
 s 15.500 \\
 12 \\
 \hline
 d 6.000
 \end{array}
 \qquad \text{Anf. } 15s 6d$$

2. What is the value of .625 shil? Anf.  $7\frac{1}{2}$ d.  
 3. What is the value of .8635l? Anf. 17s 3 $\frac{1}{2}$ d.  
 4. What is the value of .0125lb troy? Anf. 3dwts.  
 5. What is the value of .4694lb troy?  
     Anf. 5oz 12dwt 15.744gr.  
 6. What is the value of .625 cwt? Anf. 2qr 14lb.  
 7. What is the value of .009943 miles?  
     Anf. 17yd 1ft 5.98848inc.  
 8. What is the value of .6875yd? Anf. 2qr. 3nls.  
 9. What is the value of .3375acr? Anf. 1rd 14 poles.  
 10. What is the value of 2.083hhd of wine?  
     Anf. 13.1229 gal.

## CASE III.

*To reduce Integers or Decimals to Equivalent Decimals of Higher Denominations.*

## RULE.

DIVIDE by the number of parts in the next higher denomination; continuing the operation to as many higher denominations as may be necessary, the same as in Reduction Ascending of whole numbers.

## EXAMPLES.

1. Reduce 1dwt to the decimal of a pound troy,

$$\begin{array}{r} 20 \mid 1\text{dwt} \\ 12 \mid 0\cdot05\text{ oz} \\ \hline 0\cdot004166, \text{ &c. lb. Ans.} \end{array}$$

2. Reduce 9d to the decimal of a pound. Ans. 0375l.

3. Reduce 7 drams to the decimal of a pound avoird.

Ans. 02734375lb.

4. Reduce 26d to the decimal of a l. Ans. 0010833, &c. l.

5. Reduce 2·15 lb to the decimal of a cwt.

Ans. 019196+cwt.

6. Reduce 24 yards to the decimal of a mile.

Ans. 013636, &c. mile.

7. Reduce 056 pole to the decimal of an acre.

Ans. 000235 ac.

8. Reduce 1·2 pint of wine to the decimal of a hhd.

Ans. 00238+hhd.

9. Reduce 14 minutes to the decimal of a day.

Ans. 000722, &c. da.

10. Reduce 21 pint to the decimal of a peck.

Ans. 010125 peck.

11. Reduce 23" 12" to the decimal of a minute.

NOTE, When there are several numbers, to be reduced all to the decimal of the highest:

Set the given numbers directly under each other, for dividends, proceeding orderly from the lowest denomination to the highest.

Opposite to each dividend, on the left-hand, set such a number for a divisor as will bring it to the next higher name; drawing a perpendicular line between all the divisors and dividends.

Begin at the uppermost, and perform all the divisions: only observing to let the quotient of each division, as decimal

parts,

parts, on the right-hand of the dividend next below it; so shall the last quotient be the decimal required.

## EXAMPLES.

1. Reduce  $15s\ 9\frac{3}{4}d$  to the decimal of a pound.

$$\begin{array}{r|l} 4 & .\ 3 \\ 12 & 9.75 \\ 20 & 15.8125 \\ \hline & 0.790625 \text{ Ans.} \end{array}$$

2. Reduce  $19l\ 17s\ 3\frac{1}{4}d$  to  $l.$  Anf.  $19.86354166$ , &c.  $l.$   
3. Reduce  $15s\ 6d$  to the decimal of a  $l.$  Anf.  $.775l.$   
4. Reduce  $7\frac{1}{2}d$  to the decimal of a shilling. Anf.  $.625s.$   
5. Reduce  $5oz\ 12dwts\ 16gr$  to lb. Anf.  $.46944$ , &c. lb.

## RULE OF THREE IN DECIMALS.

KYLE.

PREPARE the terms by reducing, the vulgar fractions to decimals, any compound numbers either to decimals of the higher denominations, or to integers of the lower, also the first and third terms to the same name: Then multiply and divide as in whole numbers.

*Note.* Any of the convenient Examples in the Rule of Three or Rule of Five in Integers, or Vulgar Fractions, may be taken as proper examples to the same rules in Decimals.—The following Example, which is the first in Vulgar Fractions, is wrought out here, to shew the method.

If  $\frac{1}{3}$  of a yard of velvet cost  $\frac{4}{5}l$ , what will  $\frac{5}{16}$  yd cost?

$$\begin{array}{r} \text{yd} \quad l \quad \text{yd} \quad l \quad s \quad d \\ \cdot375 : \cdot4 :: \cdot3125 : \cdot333, \text{ &c., or } 6 \cdot8 \\ \qquad\qquad\qquad \cdot4 \\ \cdot375 = \cdot4 \\ \cdot375) \overline{12500} \quad (\cdot333333, \text{ &c.} \\ \qquad\qquad\qquad 1250 \qquad\qquad\qquad 20 \\ \qquad\qquad\qquad 125 \qquad\qquad\qquad \overline{s6\cdot66666, \text{ &c.}} \\ \cdot3125 = \overline{12} \\ \text{Ans. } 6s3d \end{array}$$

## DUODECIMALS.

DUODECIMALS, or CROSS MULTIPLICATION, is a rule made use of by workmen and artificers, in computing the contents of their works.

Dimensions are usually taken in feet, inches, and quarters; any parts smaller than these being neglected as of no consequence. And the same in multiplying them together, or casting up the contents.

## RULE.

SET down the two dimensions, to be multiplied together, one under the other, so that feet stand under feet, inches under inches, &c.

Multiply each term in the multiplicand, beginning at the lowest, by the feet in the multiplier, and set the result of each straight under its corresponding term, observing to carry 1 for every 12, from the inches to the feet.

In like manner, multiply all the multiplicand by the inches and parts of the multiplier, and set the result of each term one place removed to the right-hand of those in the multiplicand; omitting, however, what is below parts of inches, only carrying to these the proper number of units from the lowest denomination.

Or, instead of multiplying by the inches, take such parts of the multiplicand as these are of a foot.

Then add the two lines together, after the manner of Compound Addition, carrying 1 to the feet for 12 inches, when these come to so many.

## EXAMPLES.

1. Multiply 4f 7inc

by 6 4

27 6

1 6 $\frac{1}{2}$

Anf. 29 0 $\frac{1}{2}$

2. Multiply 14f 9inc.

by 4 6

59 0

7 4 $\frac{1}{2}$

Anf. 66 4 $\frac{1}{2}$

3. Multiply 4 feet 7 inches by 9 f 6 inc. Anf. 43f. 6 $\frac{1}{2}$  inc.

4. Multiply 12f 5inc by 6f 8inc. Anf. 82 9 $\frac{1}{3}$

5. Multiply 35f 4 $\frac{1}{2}$  inc by 12f 3inc. Anf. 433 4 $\frac{1}{3}$

6. Multiply 64f 6inc by 8f 9 $\frac{1}{4}$  inc. Anf. 565 8 $\frac{1}{2}$

## INVOLUTION.

INVOLUTION is the raising of Powers from any given number, as a root.

A Power is a quantity produced by multiplying any given number, called the Root, a certain number of times continually by itself. Thus,

$2 = 2$  is the root, or 1st power of 2.

$2 \times 2 = 4$  is the 2d power, or square of 2.

$2 \times 2 \times 2 = 8$  is the 3d power, or cube of 2.

$2 \times 2 \times 2 \times 2 = 16$  is the 4th power of 2, &c.

And in this manner may be calculated the following Table of the first nine powers of the first 9 numbers.

TABLE of the first NINE POWERS of NUMBERS.

1st	2d	3d	4th	5th	6th	7th	8th	9th
1	1	1	1	1	1	1	1	1
2	4	8	16	32	64	128	256	512
3	9	27	81	243	729	2187	6561	19683
4	16	64	256	1024	4096	16384	65536	262144
5	25	125	625	3125	15625	78125	390625	1953125
6	36	216	1296	7776	46656	279936	1679616	10077696
7	49	343	2401	16807	117649	823543	5764801	40353607
8	64	512	4096	32768	262144	2097152	16777216	134217728
9	81	729	6561	59049	531441	4782969	43046721	387420489

The Index or Exponent of a Power, is the number denoting the height or degree of that power; and it is 1 more than the number of multiplications used in producing the same. So 1 is the index or exponent of the 1st power or root, 2 of the 2d power or square, 3 of the third power or cube, 4 of the 4th power, and so on.

Powers, that are to be raised, are usually denoted by placing the index above the root or first power.

So  $2^2 = 4$  is the 2d power of 2.

$2^3 = 8$  is the 3d power of 2.

$2^4 = 16$  is the 4th power of 2.

$540^4$  is the 4th power of 540, &c.

When two or more powers are multiplied together, their product will be that power whose index is the sum of the exponents of the factors or powers multiplied. Or the multiplication of the powers, answers to the addition of the indices. Thus, in the following powers of 2,

1st	2d	3d	4th	5th	6th	7th	8th	9th	10th
2	4	8	16	32	64	128	256	512	1024
or $2^1$	$2^2$	$2^3$	$2^4$	$2^5$	$2^6$	$2^7$	$2^8$	$2^9$	$2^{10}$

Here,  $4 \times 4 = 16$ , and  $2 + 2 = 4$  its index;

and  $8 \times 16 = 128$ , and  $3 + 4 = 7$  its index;

also  $16 \times 64 = 1024$ , and  $4 + 6 = 10$  its index;

#### OTHER EXAMPLES.

- What is the 2d power of 45? Anf. 2025.
- What is the square of 4·16? Anf. 17·3056.
- What is the 3d power of 3·5? Anf. 42·875.
- What is the 5th power of .029? Anf. ·00000020511149.
- What is the square of  $\frac{2}{3}$ ? Anf.  $\frac{4}{9}$ .
- What is the 3d power of  $\frac{5}{9}$ ? Anf.  $\frac{125}{729}$ .
- What is the 4th power of  $\frac{3}{4}$ ? Anf.  $\frac{81}{256}$ .

## EVOLUTION.

EVOLUTION, or the reverse of Involution, is the extracting or finding the roots of any given powers.

The root of any number, or power, is such a number, as being multiplied into itself a certain number of times, will produce that power. Thus, 2 is the square-root or 2d root of 4, because  $2^2 = 2 \times 2 = 4$ ; and 3 is the cube-root or 3d root of 27, because  $3^3 = 3 \times 3 \times 3 = 27$ .

Any power of a given number or root may be found exactly, namely, by multiplying the number continually into itself. But there are many numbers of which a proposed root can never be exactly found. Yet, by means of decimals we may approximate or approach towards the root, to any degree of exactness.

Those roots which only approximate, are called Surd roots; but those which can be found quite exact, are called Rational roots. Thus, the square root of 3 is a surd root; but the square root of 4 is a rational root, being equal to 2: also the cube root of 8 is rational, being equal to 2; but the cube root of 9 is surd or irrational.

Roots are sometimes denoted by writing the character  $\sqrt{}$  before the power, with the index of the root against it. Thus, the 3d root of 20 is expressed by  $\sqrt[3]{20}$ ; and the square root or 2d root of it is  $\sqrt{20}$ , the index 2 being always omitted, when the square root is designed.

When the power is expressed by several numbers, with the sign + or - between them, a line is drawn from the top of the sign over all the parts of it: thus the third root of  $45 - 12$  is  $\sqrt[3]{45 - 12}$ , or thus  $\sqrt[3]{(45 - 12)}$ , inclosing the numbers in parentheses.

But all roots are now often designed like powers with fractional indices: thus, the square root of 8 is  $8^{\frac{1}{2}}$ , the cube root of 25 is  $25^{\frac{1}{3}}$ , and the 4th root of  $45 - 18$  is  $\sqrt[4]{45 - 18}^{\frac{1}{4}}$ , or  $(45 - 18)^{\frac{1}{4}}$ .

## TO EXTRACT THE SQUARE ROOT.

## RULE.\*

DIVIDE the given number into periods of two figures each; by setting a point over the place of units, another over the place of hundreds, and so on, over every second figure, both to the left-hand in integers, and to the right in decimal.

\* The reason for separating the figures of the dividend into periods or portions of two places each, is, that the square of any single figure never consists of more than two places; the square of a number of two figures, of not more than four places, and so on. So that there will be as many figures in the root as the given number contains periods so divided or parted off.

And the reason of the several steps in the operation appears from the algebraic form of the square of any number of terms, whether two or three or more. Thus,

$a + b^2 = a^2 + 2ab + b^2 = a^2 + 2a + b \cdot b$ , the square of two terms; where it appears that  $a$  is the first term of the root, and  $b$  the second term; also  $a$  the first divisor, and the new divisor is  $2a + b$ , or double the first term increased by the second. And hence the manner of extraction is thus:

1st divisor  $a$ )  $a^2 + 2ab + b^2$  ( $a + b$  the root.  
 $a^2$

$$\begin{array}{c} \overline{2a+b} \\ b \left| \begin{array}{r} 2ab + b^2 \\ 2ab + b^2 \end{array} \right. \end{array}$$

Again, for a root of three parts  $a, b, c$ , thus:

$$\begin{aligned} a + b + c^2 &= a^2 + 2ab + b^2 + 2ac + 2bc + c^2 = \\ &a^2 + 2a + b \cdot b + 2a + 2b + c \cdot c, \end{aligned}$$

square of three terms; where  $a$  is the first term of the root,  $b$  the second, and  $c$  the third term; also  $a$  the first divisor,  $2a + b$  the second, and  $2a + 2b + c$  the third, each consisting of the double of the root increased by the next term of the same. And the mode of extraction is thus:

1st divisor  $a$ )  $a^2 + 2ab + b^2 + 2ac + 2bc + c^2$  ( $a + b + c$  the root.

$$\overline{a^2}$$

$$\begin{array}{c} \overline{2a+b} \\ b \left| \begin{array}{r} 2ab + b^2 \\ 2ab + b^2 \end{array} \right. \end{array}$$

$$\begin{array}{c} \overline{2a+2b+c} \\ c \left| \begin{array}{r} 2ac + 2bc + c^2 \\ 2ac + 2bc + c^2 \end{array} \right. \end{array}$$

Find the greatest square in the first period on the left-hand, and set its root on the right-hand of the given number, after the manner of a quotient figure in Division.

Subtract the square thus found from the said period, and to the remainder annex the two figures of the next following period, for a dividend.

Double the root above mentioned for a divisor; and find how often it is contained in the said dividend, exclusive of its right-hand figure; and set that quotient figure both in the quotient and divisor.

Multiply the whole augmented divisor by this last quotient figure, and subtract the product from the said dividend, bringing down to it the next period of the given number, for a new dividend.

Repeat the same process over again; viz. find another new divisor, by doubling all the figures now found in the root; from which, and the last dividend, find the next figure of the root as before; and so on through all the periods, to the last.

*Note.* The best way of doubling the root, to form the new divisors, is by adding the last figure always to the last divisor, as appears in the following examples.—Also, after the figures belonging to the given number are all exhausted, the operation may be continued into decimals at pleasure, by adding any number of periods of ciphers, two in each period.

#### EXAMPLES.

1. To find the square root of 29506624.

$$\begin{array}{r}
 & & & 29506624 \text{ ( 5432 the root.)} \\
 & & & 25 \\
 \hline
 104 & | & 450 \\
 4 & | & 416 \\
 \hline
 1083 & | & 3466 \\
 3 & | & 3249 \\
 \hline
 10862 & | & 21724 \\
 2 & | & 21724
 \end{array}$$

NOTE,

NOTE, When the root is to be extracted to many places of figures, the work may be considerably shortened, thus:

Having proceeded in the extraction after the common method, till there be found half the required number of figures in the root, or one figure more; then, for the rest, divide the last remainder by its corresponding divisor after the manner of the third contraction in Division of Decimals; thus,

2. To find the root of 2 to nine places of figures.

$$\begin{array}{r}
 2 \text{ (} 1.41421356 \text{ the root.} \\
 \overline{1} \\
 \begin{array}{c|cc}
 24 & 100 \\
 4 & 96 \\
 \hline
 281 & 400 \\
 1 & 281 \\
 \hline
 2824 & 11900 \\
 4 & 11296 \\
 \hline
 28282 & 60400 \\
 2 & 56564 \\
 \hline
 28284 ) & 3836 ( 1356 \\
 \dots & 1008 \\
 & 160 \\
 & 19 \\
 & 2
 \end{array}
 \end{array}$$

- |  |                |
|--|----------------|
| 3. What is the square root of 2025?    | Anf. 45.       |
| 4. What is the square root of 17.3056? | Anf. 4.16.     |
| 5. What is the square root of .000729? | Anf. .027.     |
| 6. What is the square root of 3?       | Anf. 1.732050. |
| 7. What is the square root of 5?       | Anf. 2.236068. |
| 8. What is the square root of 6?       | Anf. 2.449489. |
| 9. What is the square root of 7?       | Anf. 2.645751. |
| 10. What is the square root of 10?     | Anf. 3.162277. |
| 11. What is the square root of 11?     | Anf. 3.316624. |
| 12. What is the square root of 12?     | Anf. 3.464101. |

#### RULES FOR THE SQUARE ROOTS OF VULGAR FRACTIONS AND MIXED NUMBERS.

FIRST prepare all vulgar fractions, by reducing them to their least terms, both for this and all other roots. Then

1. Take the root of the numerator and of the denominator for the respective terms of the root required. And this is the

best way if the denominator be a complete power: but if it be not, then

2. Multiply the numerator and denominator together; take the root of the product: this root being made the numerator to the denominator of the given fraction, or made the denominator to the numerator of it, will form the fractional root required.

$$\text{That is, } \sqrt{\frac{a}{b}} = \frac{\sqrt{a}}{\sqrt{b}} = \frac{\sqrt{ab}}{b} = \frac{a}{\sqrt{ab}}.$$

And this rule will serve whether the root be finite or infinite.

3. Or reduce the vulgar fraction to a decimal, and extract its root.

4. Mixed numbers may be either reduced to improper fractions, and extracted by the first or second rule; or the vulgar fraction may be reduced a decimal, then joined to the integer, and the root of the whole extracted.

#### EXAMPLES.

- |   |                       |
|---|-----------------------|
| 1. What is the root of $\frac{25}{36}$ ?  | Ansf. $\frac{5}{6}$ . |
| 2. What is the root of $\frac{27}{147}$ ? | Ansf. $\frac{3}{7}$ . |
| 3. What is the root of $\frac{9}{12}$ ?   | Ansf. 0.866025.       |
| 4. What is the root of $\frac{5}{12}$ ?   | Ansf. 0.645497.       |
| 5. What is the root of $17\frac{3}{8}$ ?  | Ansf. 4.168333.       |

By means of the square root also may readily be found the 4th root, or the 8th root, or the 16th root, &c. that is, the root of any power whose index is some power of the number 2; namely, by extracting so often the square root as is denoted by that power of 2; that is, two extractions for the 4th root, three for the 8th root, and so on.

So, to find the 4th root of the number 21035.8; extract the square root two times as follows:

21035.8000		(145.037237 (12.0431407 the 4th root.	
1	1		
24	110	22	45
4	96	2	44
285	1435	2404	10372
5	1425	4	9616
29003	108000	24083	75637
6	87009	6	72249
20991 (7237		3388	(1407
687		980	
107		17	

Ex. 2. What is the 4th root of 97.41?

## TO EXTRACT THE CUBE ROOT.

## I. By the Common Rule\*.

1. HAVING divided the given number into periods of three figures each, (by setting a point over the place of units, and also over every third figure, from thence, to the left hand in whole numbers, and to the right in decimals), find the nearest less cube to the first period; set its root in the quotient, and subtract the said cube from the first period; to the remainder bring down the second period, and call this the resolvend.

2. To three times the square of the root, just found, add three times the root itself, letting this one place more to the right than the former, and call this sum the divisor. Then divide the resolvend, wanting the last figure, by the divisor, for the next figure of the root, which annex to the former; calling this last figure  $e$ , and the part of the root before found let be called  $a$ .

3. Add all together these three products, namely, thrice  $a$  square multiplied by  $e$ , thrice  $a$  multiplied by  $e$  square, and  $e$  cube, setting each of them one place more to the right than the former, and call the sum the subtrahend; which must not exceed the resolvend; but if it does, then make the last figure  $e$  less, and repeat the operation for finding the subtrahend, till it be less than the resolvend.

4. From the resolvend take the subtrahend, and to the remainder join the next period of the given number for a new resolvend; to which form a new divisor from the whole root now found; and from thence another figure of the root, as directed in Article 2, and so on.

\* The reason for pointing the given number into periods of three figures each, is because the cube of one figure never amounts to more than three places. And, for a similar reason, a given number is pointed into periods of four figures for the 4th root, or five figures for the 5th root, and so on.

And the reason for the other parts of the rule depends on the algebraic formation of a cube: for, if the root consist of the two parts  $a + b$ , then its cube is as follows:  $a + b)^3 = a^3 + 3a^2b + 3ab^2 + b^3$ ; where  $a$  is the root of the first part  $a^3$ ; the resolvend is  $3a^2b + 3ab^2 + b^3$ , which is also the same as the three parts of the subtrahend; also the divisor is  $3a^2 + 3a$ , by which dividing the first two terms of the resolvend  $3a^2b + ab^2$ , gives  $b$  for the second part of the root; and so on.

## EXAMPLE.

To extract the cube root of 48228·544.

$$\begin{array}{r|l} 3 \times 3^2 = 27 & 48228\cdot544 \text{ (36·4 root.} \\ 3 \times 3 = 09 & 27 \\ \hline \text{Divisor } 279 & 21228 \text{ resolvend.} \end{array}$$

$$\left. \begin{array}{rcl} 3 \times 3^2 \times 6 & = & 162 \\ 3 \times 3 \times 6^2 & = & 324 \\ 6^3 & = & 216 \end{array} \right\} \text{add}$$

$$\begin{array}{r|l} 3 \times 36^2 = 3888 & 19656 \text{ subtrahend.} \\ 3 \times 36 = 108 & \hline \\ \hline 38988 & 1572544 \text{ resolvend.} \end{array}$$

$$\left. \begin{array}{rcl} 3 \times 36^2 \times 4 & = & 15552 \\ 3 \times 36 \times 4^2 & = & 1728 \\ 4^3 & = & 64 \end{array} \right\} \text{add}$$

$$1572544 \text{ subtrahend.}$$

$$0000000 \text{ remainder.}$$

Ex. 2. Extract the cube root of 571482·19.

Ex. 3. Extract the cube root of 1628·1582.

Ex. 4. Extract the cube root of 1332.

## II. To extract the Cube Root by a short Way \*.

1. By trials, or by the table of roots at p. 90, take the nearest rational cube to the given number, whether it be greater or less ; and call it the assumed cube.

2. Then say, by the Rule of Three, As the sum of the given number and double the assumed cube, is to the sum of the assumed

\* The method usually given for extracting the cube root, is so exceedingly tedious, and difficult to be remembered, that various other approximating rules have been invented, by Newton, Raphson, Halley, De Lagny, Simpson, Emerson, and several other mathematicians ; but no one that I have yet seen, is so simple in its form, or seems so well adapted for general use, as that above given. This rule, as far as I have learned, first came from Mr. James Dodson, and is the same in effect as Dr. Halley's rational formula,

assumed cube and double the given number, so is the root of the assumed cube, to the root required, nearly. Or, As the first sum is to the difference of the given and assumed cube, so is the assumed root, to the difference of the roots nearly.

3. Again, by using, in like manner, the cube of the root last found as a new assumed cube, another root will be obtained still nearer. And so on as far as we please; using always the cube of the last found root, for the assumed cube.

## EXAMPLE.

To find the cube root of 21035·8.

Here we soon find that the root lies between 20 and 30, and then between 27 and 28. Taking therefore 27, its cube is 19683, which is the assumed cube. Then

$$\begin{array}{rcc}
 19683 & 21035\cdot8 \\
 \hline
 2 & 2 \\
 39366 & 42071\cdot6 \\
 21035\cdot8 & 19683 \\
 \hline
 \text{As } 60401\cdot8 : 61754\cdot6 :: 27 : 27\cdot6047 \\
 & \hline
 & 27 \\
 & 4322822 \\
 & 1235092 \\
 60401\cdot8 ) 1667374\cdot2 & (\text{27}\cdot6047 \text{ the root nearly.} \\
 & 459338 \\
 & 36525 \\
 & 284 \\
 & 42
 \end{array}$$

Again, for a second operation, the cube of this root is 21035·318645155823, and the process by the latter method will be thus :

21035·318645, &c.

$$\begin{array}{rcc}
 42070\cdot637290 & 21035\cdot8 \\
 21035\cdot8 & 21035·318645, & \text{\&c.} \\
 \hline
 \text{As } 63106\cdot43729 : \text{diff. } 481355 :: 27\cdot6047 : \\
 & \text{the diff. } .000210560 \\
 & \hline
 \text{conseq. the root req. is } 27\cdot604910560.
 \end{array}$$

formula, but somewhat more commodiously expressed; and the first investigation of it was given in my Tracts, p. 49. The algebraic form of it is this:

$$As r + 2A : A + 2P :: r : R. \text{ Or,}$$

$$As P + 2A : P :: A :: r : R \propto r;$$

where  $r$  is the given number,  $A$  the assumed nearest cube,  $r$  the cube root of  $A$ , and  $R$  the root of  $P$  sought.

Ex. 2. To extract the cube root of .67.

Ex. 3. To extract the cube root of .01.

### TO EXTRACT ANY ROOT WHATEVER\*.

LET  $P$  be the given power or number,  $n$  the index of the power,  $A$  the assumed power,  $r$  its root,  $R$  the required root of  $P$ .

Then, as the sum of  $n+1$  times  $A$  and  $n-1$  times  $P$ , is to the sum of  $n+1$  times  $P$  and  $n-1$  times  $A$ , so is the assumed root  $r$ , to the required root  $R$ .

Or, as half the said sum of  $n+1$  times  $A$  and  $n-1$  times  $P$ , is to the difference between the given and assumed powers, so is the assumed root  $r$ , to the difference between the true and assumed roots: which difference, added or subtracted, as the case requires, gives the true root nearly.

That is,  $\overline{n+1} \cdot A + \overline{n-1} \cdot P : \overline{n+1} \cdot P + \overline{n-1} \cdot A :: r : R$ .

Or,  $\overline{n+1} \cdot \frac{1}{2}A + \overline{n-1} \cdot \frac{1}{2}P : P - A :: r : R - r$ .

And the operation may be repeated as often as we please, by using always the last found root for the assumed root, and its  $n$ th power for the assumed power  $A$ .

### EXAMPLE.

To extract the 5th root of 21035.8.

Here it appears that the 5th root is between 7.3 and 7.4. Taking 7.3, its 5th power is 20730.71593. Hence we have,  $P=21035.8$ ,  $n=5$ ,  $r=7.3$  and  $A=20730.71593$ ; then  $\overline{n+1} \cdot \frac{1}{2}A + \overline{n-1} \cdot \frac{1}{2}P : P - A :: r : R - r$ , that is,  $3 \times 20730.71593 + 2 \times 21035.8 : 305.084 :: 7.3 : R - r$ ;

3	2	7.3
62192.14779	42071.6	915252
42071.6		2135588
104263.74779 )	2227.1132(	.0213605=R - r
		7.3 = r, add.
		7.321360 = R, true to the last figure.

\* This is a very general approximating rule, of which that for the cube root is a particular case, and is the best adapted for practice, and for memory, of any that I have yet seen. It was first discovered in this form by myself, and the investigation and use of it were given at large in my Tracts, p. 45, &c.

## OTHER EXAMPLES.

- |                                      |                  |
|--------------------------------------|------------------|
| 1. What is the 3d root of 2?         | Ansf. 1.259921,  |
| 2. What is the 3d root of 3214.      | Ansf. 14.75758.  |
| 3. What is the 4th root of 2?        | Ansf. 1.189207.  |
| 4. What is the 4th root of 97.41?    | Ansf. 3.1415999. |
| 5. What is the 5th root of 2?        | Ansf. 1.148699.  |
| 6. What is the 6th root of 21035.8?  | Ansf. 5.254037.  |
| 7. What is the 6th root of 2?        | Ansf. 1.122462.  |
| 8. What is the 7th root of 21035.8?  | Ansf. 4.145392.  |
| 9. What is the 7th root of 2?        | Ansf. 1.104089.  |
| 10. What is the 8th root of 21035.8? | Ansf. 3.470323.  |
| 11. What is the 8th root of 2?       | Ansf. 1.090508.  |
| 12. What is the 9th root of 21035.8? | Ansf. 3.022239.  |
| 13. What is the 9th root of 2?       | Ansf. 1.080059.  |
- 

The following is a Table of squares and cubes, as also the square roots and cube roots, of all numbers from 1 to 1000.

## 90 A TABLE OF SQUARES, CUBES, AND ROOTS.

Number.	Square.	Cube.	Square Root.	Cube Root.
1	1	1	1·0000000	1·000000
2	4	8	1·4142136	1·259921
3	9	27	1·7320508	1·442250
4	16	64	2·0000000	1·587401
5	25	125	2·2360680	1·709976
6	36	216	2·4494897	1·817121
7	49	343	2·6457513	1·912933
8	64	512	2·8284271	2·000000
9	81	729	3·0000000	2·080084
10	100	1000	3·1622777	2·154435
11	121	1331	3·3166248	2·223380
12	144	1728	3·4641016	2·289428
13	169	2197	3·6055513	2·351335
14	196	2744	3·7416574	2·410142
15	225	3375	3·8729833	2·466212
16	256	4096	4·0000000	2·519842
17	289	4913	4·1231056	2·571282
18	324	5832	4·2426407	2·620741
19	361	6859	4·3588989	2·668402
20	400	8000	4·4721360	2·714418
21	441	9261	4·5825757	2·758923
22	484	10648	4·6904158	2·802039
23	529	12167	4·7958315	2·843867
24	576	13824	4·8989795	2·884499
25	625	15625	5·0000000	2·924018
26	676	17576	5·0990195	2·962496
27	729	19683	5·1961524	3·000000
28	784	21952	5·2915026	3·036589
29	841	24389	5·3851648	3·072317
30	900	27000	5·4772256	3·107232
31	961	29791	5·5677044	3·141381
32	1024	32768	5·6568542	3·174802
33	1089	35937	5·7445026	3·207534
34	1156	39304	5·8309519	3·239612
35	1225	42875	5·9160798	3·271066
36	1296	46656	6·0000000	3·301927
37	1369	50653	6·0827025	3·332222
38	1444	54872	6·1644140	3·361975
39	1521	59319	6·2449980	3·391211
40	1600	64000	6·3245553	3·419952
41	1681	68921	6·4031242	3·448217
42	1764	74088	6·4807407	3·476027
43	1849	79507	6·5574385	3·503398
44	1936	85184	6·6332496	3·530348
45	2025	91125	6·7082039	3·556893
46	2116	97336	6·7823300	3·583048
47	2209	103823	6·8556546	3·608826
48	2304	110592	6·9282032	3·634241
49	2401	117049	7·0000000	3·659306
50	2500	125000	7·0710678	3·684031

Number.	Square.	Cube.	Square Root.	Cube Root.
51	2001	132051	4·414284	3·705430
52	2704	140608	4·2111026	3·732511
53	2809	148877	4·2801099	3·756286
54	2916	157404	4·3484092	3·779703
55	3025	166375	4·4161985	3·802953
56	3136	175616	4·4893148	3·825862
57	3249	185193	4·5498344	3·848501
58	3364	195112	4·6157731	3·870877
59	3481	205379	4·6811457	3·892996
60	3600	216000	4·7459667	3·914807
61	3721	226981	4·8102497	3·936497
62	3844	238328	4·8740079	3·957892
63	3969	250047	4·9372539	3·979057
64	4096	262144	5·0000000	4·000000
65	4225	274625	5·0622577	4·020726
66	4356	287496	5·1240384	4·041240
67	4489	300753	5·1853528	4·061548
68	4624	314432	5·2462113	4·081656
69	4761	328509	5·3066239	4·101506
70	4900	343000	5·3666003	4·121285
71	5041	357911	5·4261498	4·140818
72	5184	373248	5·4852814	4·160168
73	5329	389017	5·5440037	4·179339
74	5476	405224	5·6023253	4·198336
75	5625	421875	5·6602540	4·217103
76	5776	438976	5·7177979	4·235824
77	5929	456533	5·7749644	4·254321
78	6084	474552	5·8317609	4·272659
79	6241	493039	5·8881944	4·290841
80	6400	512000	5·9442719	4·308870
81	6561	531441	6·0000000	4·320749
82	6724	551368	6·0553851	4·344481
83	6889	571787	6·1104336	4·362071
84	7056	592704	6·1651514	4·379519
85	7225	614125	6·2195445	4·396830
86	7396	636056	6·2736185	4·414005
87	7569	658503	6·3273791	4·431047
88	7744	681472	6·3808315	4·447960
89	7921	704969	6·4339811	4·464745
90	8100	729000	6·4868330	4·481405
91	8281	753571	6·5393920	4·497942
92	8464	778088	6·5916630	4·514357
93	8649	804357	6·6436508	4·530655
94	8836	830584	6·6953597	4·546836
95	9025	857375	6·7467943	4·502903
96	9216	884736	6·7979590	4·578857
97	9409	912673	6·8488578	4·594701
98	9604	941192	6·8994949	4·610430
99	9801	970299	6·9495744	4·626005
100	10000	1000000	10·0000000	4·641559

## ARITHMETIC.

Number.	Square.	Cube.	Sq. are Root.	Cube Root.
101	10201	1030501	10.0498756	4.657010
102	10404	1061208	10.0995049	4.672330
103	10609	1092727	10.1488916	4.687548
104	10816	1124864	10.1980390	4.702669
105	11025	1157625	10.2469508	4.717694
106	11236	1191016	10.2956301	4.732624
107	11449	1225043	10.3440804	4.747459
108	11664	1259712	10.3923048	4.762203
109	11881	1295029	10.4403065	4.776856
110	12100	1331000	10.4880855	4.791420
111	12321	1367031	10.5356538	4.805896
112	12544	1404928	10.5830052	4.820284
113	12769	1442897	10.6301458	4.834588
114	12996	1481544	10.6770783	4.848808
115	13225	1520875	10.7238053	4.862944
116	13456	1560896	10.7703206	4.876999
117	13689	1601013	10.8166538	4.890973
118	13924	1643032	10.8627805	4.904868
119	14161	1685159	10.9087121	4.918685
120	14400	1728000	10.9544512	4.932424
121	14641	1771561	11.0000000	4.940088
122	14884	1815848	11.0453610	4.959075
123	15129	1860867	11.0905305	4.973190
124	15376	1906624	11.1355287	4.986631
125	15625	1953125	11.1803399	5.000000
126	15876	2000376	11.2249722	5.013298
127	16129	2048383	11.2694277	5.026526
128	16384	2097152	11.3137085	5.039084
129	16641	2146689	11.3578167	5.052774
130	16900	2197000	11.4017543	5.065797
131	17161	2248091	11.4455231	5.078753
132	17424	2299968	11.4891253	5.091643
133	17689	2352037	11.5325626	5.104469
134	17956	2406104	11.5758369	5.117230
135	18225	2460375	11.6189500	5.129928
136	18496	2515456	11.6619038	5.142563
137	18769	2571353	11.7046999	5.155137
138	19044	2628072	11.7473444	5.167649
139	19321	2685019	11.7898261	5.180101
140	19600	2744000	11.8321506	5.192494
141	19881	2803221	11.8743421	5.204828
142	20164	2863288	11.9163753	5.217103
143	20449	2924207	11.9582607	5.229321
144	20736	2985984	12.0000000	5.241482
145	21025	3048625	12.0415946	5.253588
146	21316	3112136	12.0830460	5.265637
147	21609	3176523	12.1243557	5.277632
148	21904	3241792	12.1655251	5.289572
149	22201	3307949	12.2005556	5.301459
150	22500	3375000	12.2474487	5.313293

Number.	Square.	Cube.	Square Root.	Cube Root.
151	22801	3442951	12.2882057	5.325074
152	23104	3511808	12.3288280	5.336803
153	23409	3581577	12.3693169	5.348481
154	23716	3652264	12.4096736	5.360108
155	24025	3723875	12.4498995	5.371685
156	24336	3796416	12.4899900	5.383213
157	24649	3869893	12.5299641	5.394690
158	24964	3944312	12.5698051	5.406120
159	25281	4019679	12.6095202	5.417501
160	25600	4096000	12.6491100	5.428835
161	25921	4173281	12.6885775	5.440122
162	26244	4251528	12.7279221	5.451362
163	26569	4330747	12.7671453	5.462556
164	26896	4410944	12.8062485	5.473703
165	27225	4492125	12.8452326	5.484806
166	27556	4574296	12.8840987	5.495865
167	27889	4657463	12.9228480	5.506879
168	28224	4741632	12.9614814	5.517848
169	28561	4826809	13.0000000	5.528775
170	28900	4913000	13.0384048	5.539658
171	29241	5000211	13.0766968	5.550499
172	29584	5088448	13.1148770	5.561298
173	29929	5177717	13.1529464	5.572054
174	30276	5268024	13.1909000	5.582770
175	30625	5359375	13.2287566	5.593445
176	30976	5451776	13.2664992	5.604079
177	31329	5545233	13.3041347	5.614673
178	31684	5639752	13.3416641	5.625226
179	32041	5735339	13.3790882	5.635741
180	32400	5832000	13.4164079	5.646216
181	32761	5929741	13.4536240	5.656652
182	33124	6028568	13.4907376	5.667051
183	33489	6128487	13.5277493	5.677411
184	33856	6229504	13.5646600	5.687734
185	34225	6331625	13.6014705	5.698019
186	34596	6434856	13.6381817	5.708267
187	34969	6539293	13.6747943	5.718479
188	35344	6644672	13.7113092	5.728654
189	35721	6751269	13.7477271	5.738794
190	36100	6859000	13.7840488	5.748897
191	36181	6967871	13.8202750	5.758965
192	36564	7077588	13.8564065	5.768998
193	37249	7189057	13.8924440	5.778996
194	37636	7301384	13.9283883	5.788960
195	38025	7414875	13.9642400	5.798890
196	38416	7529536	14.0000000	5.808786
197	38809	7645373	14.0356688	5.818648
198	39204	7762392	14.0712473	5.828476
199	39601	7880599	14.1067360	5.838272
200	40000	8000000	14.1421356	5.848035

## ARITHMETIC.

Number.	Square.	Cube	Square Root.	Cube Root.
201	40401	8120001	14.1774469	5.857705
202	40804	8242408	14.2126704	5.867464
203	41209	8365427	14.2478068	5.877130
204	41616	8489664	14.2828569	5.886765
205	42025	8615125	14.3178211	5.896368
206	42436	8741816	14.3527001	5.905941
207	42849	8869743	14.3874946	5.915481
208	43264	8998912	14.4222051	5.924994
209	43681	9123329	14.4568323	5.934473
210	44100	9261000	14.4913767	5.943911
211	44521	9393931	14.5258390	5.953341
212	44944	9528128	14.5602198	5.962731
213	45369	9663597	14.5945195	5.972091
214	45796	9800344	14.6287388	5.981426
215	46225	9938375	14.6628783	5.990727
216	46656	10077696	14.6969385	6.000000
217	47089	10218313	14.7309199	6.009244
218	47524	10360282	14.7648231	6.018463
219	47961	10503459	14.7986486	6.027650
220	48400	10645000	14.8323970	6.036811
221	48841	10793861	14.8660687	6.045943
222	49284	10941048	14.8996644	6.055048
223	49729	11089567	14.9331845	6.064126
224	50176	11239424	14.9666295	6.073177
225	50625	11390625	15.0000000	6.082201
226	51076	11543176	15.0332964	6.091199
227	51529	11697083	15.0665192	6.100170
228	51984	11852352	15.0996689	6.109115
229	52441	12008989	15.1327460	6.118032
230	52900	12167000	15.1657509	6.126925
231	53361	12326391	15.1986842	6.135792
232	53824	12487169	15.2315462	6.144634
233	54289	12649337	15.2643375	6.153449
234	54756	12812904	15.2970585	6.162239
235	55225	12977875	15.3297007	6.171005
236	55696	13144256	15.3622915	6.179747
237	56169	13312053	15.3948043	6.188463
238	56644	13481272	15.4272486	6.197154
239	57121	13651919	15.4596248	6.205821
240	57600	13824000	15.4919334	6.21464
241	58081	13997521	15.5241747	6.223083
242	58564	14172488	15.5563492	6.231678
243	59049	14348907	15.5884573	6.240251
244	59536	14526784	15.6204994	6.248800
245	60025	14706125	15.6524758	6.257324
246	60516	14886936	15.6843871	6.265826
247	61009	15069223	15.7162336	6.274304
248	61504	15252992	15.7480157	6.282760
249	62001	15438249	15.7797338	6.291194
250	62500	15625000	15.8113883	6.299604

Numb.	Square.	Cube.	Square Root.	Cube Root.
251	63001	15813251	15.8429795	6.307992
252	63504	16003008	15.8745079	6.310359
253	64009	16194277	15.9059737	6.324704
254	64516	16387064	15.9373775	6.333025
255	65025	16581375	15.9687194	6.341325
256	65536	16777216	16.0000000	6.349602
257	66049	16974593	16.0312195	6.357859
258	66564	17173512	16.0623784	6.366095
259	67081	17373979	16.0934769	6.374310
260	67600	17576000	16.1245155	6.382504
261	68121	17779581	16.1554944	6.390676
262	68644	17984728	16.1864141	6.398827
263	69169	18191447	16.2172747	6.406958
264	69696	18399744	16.2480708	6.415068
265	70225	18609625	16.2788206	6.423157
266	70756	18821096	16.3095064	6.431226
267	71289	19034163	16.3401346	6.439275
268	71824	19248832	16.3707055	6.447305
269	72361	19465109	16.4012195	6.455314
270	72900	19683000	16.4316767	6.463304
271	73441	19902511	16.4620776	6.471274
272	73984	20123648	16.4924225	6.479224
273	74529	20346417	16.5227116	6.487153
274	75076	20570824	16.5529454	6.495064
275	75625	20796875	16.5831240	6.502956
276	76176	21024576	16.6132477	6.510829
277	76729	21253933	16.6433170	6.518684
278	77284	21484952	16.6733320	6.526519
279	77841	21717639	16.7032931	6.534335
280	78400	21952000	16.7332005	6.542132
281	78961	22188041	16.7630546	6.549911
282	79524	22425768	16.7928556	6.557672
283	80089	22665187	16.8226038	6.563415
284	80650	22906304	16.8522995	6.573139
285	81225	23149125	16.8819430	6.580844
286	81796	23393656	16.9115345	6.588531
287	82369	23639903	16.9410743	6.596202
288	82944	23887872	16.9705627	6.603854
289	83521	24137569	17.0000000	6.611488
290	84100	24389000	17.0293864	6.619106
291	84681	24642171	17.0587221	6.626705
292	85264	24897088	17.0880075	6.634287
293	85849	25153757	17.1172428	6.641851
294	86436	25412184	17.1464282	6.649399
295	87025	25672375	17.1755640	6.656930
296	87616	25934336	17.2046505	6.664443
297	88209	26198073	17.2336879	6.671940
298	88804	26463592	17.2626765	6.679419
299	89401	26730899	17.2916165	6.686882
300	90000	27000000	17.3205081	6.694328

## ARITHMETIC.

Numb.	Square.	Cube.	Square Root.	Cube Root.
301	90601	27270901	17.3493516	6.701758
302	91204	27543608	17.3781472	6.709172
303	91809	27818127	17.4068952	6.716569
304	92416	28094464	17.4355958	6.723950
305	93025	28372625	17.4642492	6.731316
306	93636	28652016	17.4928557	6.738665
307	94249	28934443	17.5214155	6.745997
308	94864	29218112	17.5499288	6.753313
309	95481	29503629	17.5783958	6.760614
310	96100	29791000	17.6068169	6.767899
311	96721	30080231	17.6351921	6.775108
312	97344	30371328	17.6635217	6.782422
313	97969	30664297	17.6918060	6.789661
314	98596	30959144	17.7200451	6.796884
315	99225	31255875	17.7482393	6.804091
316	99856	31554496	17.7763888	6.811284
317	100489	31855013	17.8044938	6.818461
318	101124	32157432	17.8325545	6.825624
319	101761	32461759	17.8605711	6.832771
320	102400	32768000	17.8885438	6.839903
321	103041	33076161	17.9164729	6.847021
322	103684	33386248	17.9443584	6.854124
323	104329	33698267	17.9722008	6.861211
324	104976	34012224	18.0000000	6.868284
325	105625	34328125	18.0277564	6.875343
326	106276	34645976	18.0554701	6.882388
327	106929	34965783	18.0831413	6.889419
328	107584	35287552	18.1107703	6.896435
329	108241	356011289	18.1383571	6.903436
330	108900	35937000	18.1659021	6.910423
331	109561	36264691	18.1934054	6.917396
332	110224	36594368	18.2208672	6.924355
333	110889	36926037	18.2482876	6.931300
334	111556	37259704	18.2756669	6.938232
335	112225	37595375	18.3030052	6.945149
336	112896	37933056	18.3303028	6.952053
337	113569	38272753	18.3575598	6.958943
338	114244	38614472	18.3847763	6.965819
339	114921	38958219	18.4119526	6.972682
340	115600	39304000	18.4390889	6.979532
341	116281	39651821	18.4661853	6.986369
342	116964	40001688	18.4932420	6.993191
343	117649	40353607	18.5202592	7.000000
344	118336	40707584	18.5472370	7.006796
345	119025	41063625	18.5741756	7.013579
346	119716	41421736	18.6010752	7.020349
347	120409	41781923	18.6279360	7.027106
348	121104	42144192	18.6547581	7.033850
349	121801	42508549	18.6815417	7.040581
350	122500	42875000	18.7082860	7.047268

Numb.	Square.	Cube.	Square Root.	Cubé Root.
351	123201	43243551	18·7349940	7·054003
352	123904	43614208	18·7616030	7·066696
353	124609	43985977	18·7882942	7·067376
354	125316	44361864	18·8148877	7·074043
355	126025	44738375	18·8414437	7·080598
356	126736	45118016	18·8679623	7·087341
357	127449	45499293	18·8944436	7·093970
358	128164	45882712	18·9208879	7·100588
359	128881	46268279	18·9472953	7·107193
360	129600	466560000	18·9736660	7·113786
361	130321	47045881	19·0000000	7·120367
362	131044	47437928	19·0262976	7·126935
363	131769	47832147	19·0525589	7·133492
364	132496	48228544	19·0787840	7·140037
365	133225	48627125	19·1049732	7·146569
366	133956	49027896	19·1311265	7·153090
367	134689	49430803	19·1572441	7·159599
368	135424	49836032	19·1833261	7·166095
369	136161	50243409	19·2093727	7·172580
370	136900	50653000	19·2353841	7·179054
371	137641	51064811	19·2613603	7·185516
372	138384	51478848	19·2873015	7·191966
373	139129	51895117	19·3132079	7·198405
374	139876	52313624	19·3390796	7·204832
375	140625	52734375	19·3649167	7·211247
376	141376	53157376	19·3907194	7·217652
377	142129	53582633	19·4164878	7·224045
378	142884	54010152	19·4422221	7·230427
379	143641	54439939	19·4679223	7·236797
380	144400	54872000	19·4935887	7·243156
381	145161	55306341	19·5192213	7·249504
382	145924	55742968	19·5448203	7·255841
383	146689	56181887	19·5703858	7·262167
384	147456	56623104	19·5959179	7·208482
385	148225	57066625	19·6214169	7·274786
386	148996	57512456	19·6468827	7·281079
387	149769	57966003	19·6723156	7·287302
388	150544	58411072	19·6977156	7·293633
389	151321	58863869	19·7230829	7·299893
390	152100	59319000	19·7484177	7·306143
391	152881	59776471	19·7737199	7·312383
392	153664	60236288	19·7989899	7·318611
393	154449	60698457	19·8242276	7·324829
394	155236	61162984	19·8494332	7·331037
395	156025	61629875	19·8746069	7·337234
396	156816	62099136	19·8997487	7·343420
397	157609	62570773	19·9248588	7·349596
398	158404	63044792	19·9499373	7·355762
399	159201	63521199	19·9749844	7·361917
400	160000	64000000	20·0000000	7·368063

## ARITHMETIC.

Numb.	Square.	Cube.	Square Root.	Cube Root.
401	160801	64481201	20.0249844	7.374198
402	161604	64964808	20.0499377	7.380322
403	162409	65450827	20.0748599	7.386437
404	163216	65939264	20.0997512	7.392542
405	164025	66430125	20.1246118	7.398636
406	164836	66923416	20.1494417	7.404720
407	165649	67419143	20.1742410	7.410794
408	166464	67911312	20.1990099	7.416859
409	167281	68417929	20.2237484	7.422914
410	168100	68921000	20.2484567	7.428958
411	168921	69426531	20.2731349	7.434993
412	169744	69934528	20.2977831	7.441018
413	170569	70444997	20.3224014	7.447033
414	171396	70957944	20.3469899	7.453039
415	172225	71473375	20.3715488	7.459036
416	173056	71991296	20.3960781	7.465022
417	173889	72511713	20.4205779	7.470999
418	174724	73034632	20.4450483	7.476966
419	175561	73560059	20.4694895	7.482924
420	176400	74088000	20.4939015	7.488872
421	177241	74618461	20.5182845	7.494810
422	178084	75151448	20.5426386	7.500740
423	178929	75686967	20.5669638	7.506660
424	179776	76225024	20.5912603	7.512571
425	180625	76765625	20.6155281	7.518473
426	181476	77308776	20.6397674	7.524365
427	182329	77854483	20.6639783	7.530248
428	183184	78402752	20.6881609	7.536121
429	184041	78953589	20.7123152	7.541986
430	184900	79507000	20.7364414	7.547841
431	185761	80062991	20.7605395	7.553688
432	186624	80621568	20.7846097	7.559525
433	187489	81182737	20.8086520	7.565353
434	188356	81746504	20.8326667	7.571173
435	189225	82312875	20.8566536	7.576984
436	190096	82881856	20.8806130	7.582786
437	190969	83453453	20.9045450	7.588579
438	191844	84027672	20.9284495	7.594363
439	192721	84604519	20.9523208	7.600138
440	193600	85184000	20.9761770	7.605905
441	194481	85766121	21.0000000	7.611662
442	195364	86350888	21.0237960	7.617411
443	196249	86938307	21.0475652	7.623151
444	197136	87528384	21.0713075	7.628883
445	198025	88121125	21.0950231	7.634606
446	198916	88716536	21.1187121	7.640321
447	199809	89314623	21.1423745	7.646027
448	200704	89915392	21.1600105	7.651725
449	201601	90518849	21.1896201	7.657414
450	202500	91125000	21.2132034	7.663094

Numb.	Square.	Cube.	Square Root.	Cube Root.
451	203401	91733851	21·2367600	7·668766
452	204304	92345408	21·2602916	7·674430
453	205209	92959677	21·2837967	7·680085
454	206116	93576664	21·3072758	7·685732
455	207025	94196375	21·3307290	7·691371
456	207936	94818816	21·3541565	7·697002
457	208849	95443993	21·3775583	7·702624
458	209764	96071912	21·4009346	7·708238
459	210681	96702579	21·4242853	7·713844
460	211600	97336000	21·4476106	7·719442
461	212521	97972181	21·4709106	7·725032
462	213444	98611128	21·4941853	7·730614
463	214369	99252847	21·5174348	7·735187
464	215296	99897344	21·5406592	7·741753
465	216225	100544625	21·5638587	7·747310
466	217156	101194696	21·5870331	7·752860
467	218089	101847563	21·6101828	7·758402
468	219024	102503232	21·6333077	7·763936
469	219961	103101709	21·6564078	7·769462
470	220900	103823000	21·6794834	7·774980
471	221841	104487111	21·7025344	7·780490
472	222784	105154048	21·7255610	7·785992
473	223729	105823817	21·7485632	7·791487
474	224676	106496424	21·7715411	7·796974
475	225625	107171875	21·7944947	7·802453
476	226576	107850176	21·8174242	7·807925
477	227529	108531333	21·8403297	7·813389
478	228484	109215352	21·8632111	7·818845
479	229441	109902239	21·8860686	7·824294
480	230400	110592000	21·9089023	7·829735
481	231361	111284641	21·9317122	7·835168
482	232324	111980168	21·9544984	7·840594
483	233289	112678587	21·9772610	7·846013
484	234256	113379904	22·0000000	7·851424
485	235225	114084125	22·0227155	7·856826
486	236196	114791256	22·0454077	7·862224
487	237169	115501303	22·0680765	7·867613
488	238144	116214272	22·0907220	7·872994
489	239121	116930169	22·1133444	7·878368
490	240100	117649000	22·1359436	7·883734
491	241081	118370771	22·1585198	7·89094
492	242064	119095488	22·1810730	7·894446
493	243049	119823157	22·2036033	7·899791
494	244036	120553784	22·2261108	7·905129
495	245025	121287375	22·2485955	7·910460
496	246016	122023936	22·2710575	7·915784
497	247009	122763473	22·2934968	7·921100
498	248004	123505992	22·3159136	7·926408
499	249001	124251499	22·3383079	7·931710
500	250000	125000000	22·3606798	7·937005

Numb.	Square.	Cube.	Square Root.	Cube Root.
501	251001	125751501	22.3830293	7.942293
502	252004	126506008	22.4053565	7.947573
503	253009	127263527	22.4276615	7.952847
504	254016	128024064	22.4499443	7.958114
505	255025	128787625	22.4722051	7.963374
506	256036	129554216	22.4944438	7.968027
507	257049	130323843	22.5166605	7.973873
508	258064	131096512	22.5388553	7.979112
509	259081	131872229	22.5610283	7.984344
510	260100	132651000	22.5831796	7.989569
511	261121	133432831	22.6053091	7.994788
512	262144	134217728	22.6274170	8.000000
513	263169	135005697	22.6495033	8.005205
514	264196	135796744	22.6715681	8.010403
515	265225	136590875	22.6936114	8.015595
516	266256	137388096	22.7156334	8.020779
517	267289	138188413	22.7376340	8.025957
518	268324	138991832	22.7596134	8.031129
519	269361	139798359	22.7815715	8.036293
520	270400	140608000	22.8035085	8.041451
521	271441	141420761	22.8254244	8.046603
522	272484	142236648	22.8473193	8.051748
523	273529	143055667	22.8691933	8.056886
524	274570	143877824	22.8910463	8.062018
525	275625	144703125	22.9128785	8.067143
526	276676	145531576	22.9346899	8.072262
527	277729	146363183	22.9564806	8.077374
528	278784	147197952	22.9782506	8.082480
529	279841	148035889	23.0000000	8.087579
530	280900	148877000	23.0217289	8.092672
531	281961	149721291	23.0434372	8.097758
532	283024	150568768	23.0651252	8.102838
533	284089	151419437	23.0867928	8.107912
534	285156	152273304	23.1084100	8.112980
535	286225	153130375	23.1300670	8.118041
536	287296	153990656	23.1516738	8.123096
537	288369	154854153	23.1732605	8.128144
538	289444	155720872	23.1948270	8.133186
539	290521	156590819	23.2163735	8.138223
540	291600	157464000	23.2379001	8.143253
541	292681	158340421	23.2594067	8.148276
542	293764	159220088	23.2808935	8.153293
543	294849	160103007	23.3023604	8.158304
544	295926	160989184	23.3238076	8.163209
545	297025	161878625	23.3452351	8.168308
546	298116	162771336	23.3666429	8.173302
547	299209	163667323	23.3880311	8.178289
548	300304	164566592	23.4093998	8.183269
549	301401	165469149	23.4307490	8.188244
550	302500	166375000	23.4520788	8.193212

Numb.	Square.	Cube.	Square Root.	Cube Root.
551	303601	167284151	23·4733892	8·193175
552	304704	168196608	23·4946802	8·203131
553	305809	169112377	23·5159520	8·208082
554	306916	170031464	23·5372046	8·213027
555	308025	170953875	23·5584380	8·217905
556	309136	171879016	23·5796522	8·222898
557	310249	172808603	23·6008474	8·227825
558	311364	173741112	23·6220236	8·232746
559	312481	174676879	23·6431803	8·237661
560	313600	175616000	23·6643191	8·242570
561	314721	176558481	23·6854386	8·247474
562	315844	177504328	23·7065392	8·252371
563	316969	178453547	23·7276110	8·257263
564	318096	179406144	23·7486842	8·262149
565	319225	180362125	23·7697286	8·267029
566	320356	181321496	23·7907545	8·271903
567	321489	182284263	23·8117018	8·276772
568	322624	183250432	23·8327505	8·281035
569	323761	184220009	23·8537209	8·286493
570	324900	185193000	23·8746728	8·291344
571	326041	186169411	23·8956003	8·296190
572	327184	187149248	23·9165215	8·301030
573	328329	188132517	23·9374184	8·305805
574	329476	189119224	23·9582971	8·310094
575	330625	190109375	23·9791576	8·315517
576	331776	191102976	24·0000000	8·320835
577	332929	192100033	24·0208243	8·325147
578	334084	193100552	24·0416306	8·329954
579	335241	194104539	24·0624183	8·334753
580	336400	195112000	24·0831892	8·339551
581	337561	196122941	24·1039416	8·344341
582	338724	197137368	24·1246762	8·349125
583	339889	198155287	24·1453929	8·353904
584	341056	199176704	24·1660919	8·358078
585	342225	200201625	24·1807732	8·363446
586	343396	201230056	24·2074369	8·368209
587	344569	202262003	24·2280829	8·372966
588	345744	203297472	24·2487113	8·377718
589	346921	204336469	24·2693222	8·382465
590	348100	205379000	24·2899156	8·387200
591	349281	206425071	24·3104076	8·391042
592	350464	207474688	24·3310591	8·395073
593	351649	208527857	24·3515913	8·401398
594	352836	209584584	24·3721152	8·406115
595	354025	210644875	24·3926218	8·410832
596	355216	211768736	24·4131112	8·415541
597	356409	212776173	24·4335834	8·420245
598	357604	213847192	24·4540385	8·424944
599	358801	214921799	24·4744765	8·429538
600	360000	216000000	24·4948374	8·434327

## ARITHMETIC.

Numb.	Square.	Cube.	Square Root.	Cube Root.
601	361201	217031801	24·5153013	8·439009
602	362404	218167208	24·5356883	8·443687
603	363609	219256227	24·5560583	8·448360
604	364816	220348864	24·5764115	8·453027
605	366025	221445125	24·5967478	8·457689
606	367236	222545016	24·6170673	8·462347
607	368449	223648543	24·6373700	8·466999
608	369664	224755712	24·6576560	8·471647
609	370881	225866529	24·6779254	8·476289
610	372100	226981000	24·6981781	8·480926
611	373321	228099131	24·7184142	8·485557
612	374544	229220928	24·7386338	8·490184
613	375769	230346397	24·7588368	8·494806
614	376996	231475544	24·7790234	8·499423
615	378225	232608375	24·7991935	8·504034
616	379456	233744896	24·8193473	8·508641
617	380689	234885113	24·8394847	8·513243
618	381924	236029032	24·8596058	8·517840
619	383161	237176659	24·8797106	8·522432
620	384400	238328000	24·8997992	8·527018
621	385641	239483061	24·9198716	8·531600
622	386884	240641848	24·9399278	8·536177
623	388129	241804367	24·9599679	8·540749
624	389376	242970624	24·9799920	8·545317
625	390625	244140625	25·0000000	8·549879
626	391876	245314376	25·0199920	8·554437
627	393129	246491883	25·0399681	8·558990
628	394384	247673152	25·0599282	8·563537
629	395641	248858189	25·0798724	8·568080
630	396900	250047000	25·0998008	8·572618
631	398161	251239591	25·1197134	8·577152
632	399424	252435968	25·1396102	8·581680
633	400689	253636137	25·1594913	8·586204
634	401956	254840104	25·1793566	8·590723
635	403225	256047875	25·1992063	8·595238
636	404496	257259456	25·2190404	8·599747
637	405769	258474853	25·2388589	8·604252
638	407044	259694072	25·2586619	8·608752
639	408321	260917119	25·2784493	8·613248
640	409600	262144000	25·2982213	8·617738
641	410881	263374721	25·3179778	8·622224
642	412164	264609288	25·3377189	8·626706
643	413449	265847707	25·3574447	8·631183
644	414736	267089984	25·3771551	8·635655
645	416025	268336125	25·3968502	8·640122
646	417316	269586136	25·4165301	8·644585
647	418609	270840023	25·4361947	8·649043
648	419904	272097792	25·4558441	8·653497
649	421201	273359449	25·4754784	8·657946
650	422500	274625000	25·4950076	8·662301

Numb.	Square.	Cube.	Square Root.	Cube Root.
651	423801	275894451	25.5147016	8.060831
652	425104	277167808	25.5342907	8.071266
653	426409	278445077	25.5538647	8.075697
654	427716	279726264	25.5734237	8.080123
655	429025	281011375	25.5929678	8.084545
656	430336	282300416	25.6124969	8.088963
657	431649	283593393	25.6320112	8.093376
658	432964	284890312	25.6515107	8.097784
659	434281	286191179	25.6709953	8.702183
660	435600	287496000	25.6904652	8.706587
661	436921	288804781	25.7099203	8.710982
662	438244	290117528	25.7203607	8.715373
663	439569	291434247	25.7487864	8.719759
664	440896	292754944	25.7681975	8.724141
665	442225	294079625	25.7875939	8.728518
666	443556	295408296	25.8069758	8.732891
667	444889	296740963	25.8263431	8.737200
668	446224	298077632	25.8456960	8.741624
669	447561	299418309	25.8650343	8.745984
670	448900	300763000	25.8845582	8.750340
671	450241	302111711	25.9036677	8.754691
672	451584	303464448	25.9229628	8.759038
673	452929	304821217	25.9422435	8.763380
674	454276	306182024	25.9615100	8.767719
675	455625	307546875	25.9807621	8.772053
676	456976	308915776	26.0000000	8.776382
677	458329	310288733	26.0192237	8.780703
678	459684	311665752	26.0384331	8.785029
679	461041	313040839	26.0576284	8.789346
680	462400	314432000	26.0768063	8.793659
681	463761	315821241	26.0959767	8.797967
682	465124	317214568	26.1151297	8.802272
683	466489	318611987	26.1342687	8.806572
684	467856	320013504	26.1533937	8.810868
685	469225	321419125	26.1725047	8.815159
686	470596	322818856	26.1916017	8.819447
687	471969	324242703	26.2106848	8.823730
688	473344	325660672	26.2297541	8.826009
689	474721	327082769	26.2488095	8.832285
690	476100	328509300	26.2678511	8.830556
691	477481	329939371	26.2868789	8.840822
692	478864	331373888	26.3058929	8.845085
693	480249	332812557	26.3248932	8.849344
694	481636	334255384	26.3438797	8.853598
695	483025	335702375	26.3628527	8.857849
696	484416	337153536	26.3818119	8.862095
697	485809	338608873	26.4007576	8.866337
698	487204	340068392	26.4196896	8.870575
699	488601	341532099	26.4386081	8.874809
700	490000	343000000	26.4575131	8.879040

## ARITHMETIC.

Numb.	Square.	Cube.	Square Root.	Cube Root.
701	491401	344472101	20.4704046	8.883266
702	492804	345948008	20.4952826	8.887488
703	494209	347428927	20.5141472	8.891706
704	495616	348913664	20.5329983	8.895920
705	497025	350402625	20.5518361	8.900130
706	498436	351895816	20.5700605	8.904336
707	499849	353393243	20.5894716	8.908538
708	501264	354894912	20.6082694	8.912736
709	502681	356400829	20.6270539	8.916931
710	504100	357911000	20.6458252	8.921121
711	505521	359425431	20.6645833	8.925307
712	506944	360944128	20.6833281	8.929490
713	508369	362467097	20.7020598	8.933008
714	509796	363994344	20.7207784	8.937843
715	511225	365525875	20.7394839	8.942014
716	512656	367061696	20.7581703	8.946180
717	514089	368601813	20.7768557	8.950343
718	515524	370140232	20.7955220	8.954502
719	516961	371694959	20.8141754	8.958058
720	518400	373248000	20.8328157	8.962509
721	519841	374805361	20.8514432	8.966957
722	521284	376307048	20.8700577	8.971100
723	522729	377933007	20.8886593	8.975240
724	524176	379503424	20.9072481	8.979376
725	525625	381078125	20.9258240	8.983508
726	527076	382657176	20.9443872	8.987037
727	528529	384240583	20.9629375	8.991762
728	529984	385828352	20.9814751	8.995883
729	531441	387420489	20.0000000	9.000000
730	532900	389017000	20.0185122	9.004113
731	534361	390617891	20.0370117	9.008222
732	535824	392223168	20.0554985	9.012328
733	537289	393832837	20.0739727	9.016430
734	538756	395446904	20.0924344	9.020529
735	540225	397065375	20.1108834	9.024023
736	541696	398688256	20.1293199	9.028714
737	543169	400315553	20.1477439	9.032802
738	544644	401947272	20.1661554	9.036885
739	546121	403583419	20.1845544	9.040965
740	547600	405224000	20.2029410	9.045041
741	549081	406809021	20.2213152	9.049114
742	550564	408518488	20.2396769	9.053183
743	552049	410172407	20.2580263	9.057248
744	553536	411830784	20.2703634	9.061309
745	555025	413493625	20.2946881	9.065367
746	556516	415160036	20.3130006	9.069422
747	558009	416832723	20.3313007	9.073472
748	559504	418508992	20.3495887	9.077519
749	561001	420189749	20.3678644	9.081563
750	562500	421875000	20.3861279	9.085603

Numb.	Square.	Cube.	Square Root.	Cube Root.
751	564001	423504751	27.4043792	9.089039
752	565504	425259008	27.4220184	9.093672
753	567009	426957777	27.4408455	9.097701
754	568516	428601004	27.4590004	9.101726
755	570025	430368875	27.4772033	9.105748
756	571533	432081216	27.4954542	9.109766
757	573049	433798093	27.5136330	9.113781
758	574564	435519512	27.5317998	9.117793
759	576081	437245479	27.5499546	9.121801
760	577600	438976000	27.5680975	9.125805
761	579121	440711081	27.5862284	9.129806
762	580644	442450728	27.6043475	9.133803
763	582169	444194947	27.6224546	9.137797
764	583690	445943744	27.6405499	9.141788
765	585225	447697125	27.6586334	9.145774
766	586750	449455096	27.6767050	9.149757
767	588289	451217663	27.6947648	9.153737
768	589824	452984832	27.7128129	9.157713
769	591361	454756609	27.7308492	9.161686
770	592900	456533000	27.7488739	9.165656
771	594441	458314011	27.7668868	9.169622
772	595984	460099648	27.7848880	9.173585
773	597529	461889917	27.8028775	9.177544
774	599076	463684824	27.8208555	9.181500
775	600625	465484375	27.8388218	9.185452
776	602176	467288576	27.8567766	9.189401
777	603729	469097433	27.8747197	9.193347
778	605284	470910952	27.8920514	9.197289
779	606841	472729139	27.9105715	9.201228
780	608400	474552000	27.9284801	9.205164
781	609961	476379541	27.9463772	9.209096
782	611524	478211768	27.9642629	9.213025
783	613089	480048687	27.9821372	9.216950
784	614656	481890304	28.0000000	9.220872
785	616225	483736025	28.0178515	9.224791
786	617796	485587656	28.0356915	9.228706
787	619369	487443403	28.0535203	9.232618
788	620944	489303872	28.0713377	9.237527
789	622521	491169069	28.0891438	9.240433
790	624100	493039000	28.1009386	9.244335
791	625681	494913671	28.1247222	9.248234
792	627264	496793088	28.1424946	9.252130
793	628849	498677257	28.1602557	9.256022
794	630436	500566184	28.1780056	9.259911
795	632025	502459875	28.1957444	9.263797
796	633616	504358336	28.2134720	9.267679
797	635209	506201573	28.2311884	9.271559
798	636804	508169592	28.2488938	9.275435
799	638401	510082399	28.2605881	9.279308
800	640000	512000000	28.2842712	9.283177

## ARITHMETIC.

Numb.	Square.	Cube.	Square Root.	Cube Root
801	641601	513922401	28.3019434	9.257044
802	643204	515349608	28.3196045	9.290907
803	644809	517781627	28.3372546	9.294707
804	646416	519718464	28.3548938	9.298623
805	648025	521600125	28.3725219	9.302477
806	649636	523606616	28.3901391	9.306327
807	651249	525557943	28.4077454	9.310175
808	652864	527514112	28.4253408	9.314019
809	654481	529475129	28.4429253	9.317859
810	656100	531441000	28.4604989	9.321697
811	657721	533411731	28.4780617	9.325532
812	659344	535387328	28.4956137	9.329363
813	660969	537366797	28.5131549	9.333191
814	662596	539353144	28.5306952	9.337016
815	664225	541343375	28.5482048	9.340838
816	665856	543338496	28.5657137	9.344657
817	667489	545338513	28.5832119	9.348473
818	669124	547343432	28.6000993	9.352285
819	670761	549353259	28.6181760	9.356095
820	672400	551368000	28.6356421	9.359901
821	674041	553387661	28.6530976	9.363704
822	675684	555412248	28.6705424	9.367505
823	677329	557441767	28.6879766	9.371362
824	678976	559476224	28.7054002	9.375006
825	680625	561515625	28.7229132	9.378887
826	682276	563559976	28.7402157	9.382675
827	683929	565609283	28.7576077	9.386460
828	685584	567663552	28.7740891	9.390241
829	687241	569722789	28.7923601	9.394020
830	688900	571787000	28.8097206	9.397796
831	690561	573856191	28.8270706	9.401569
832	692224	575930368	28.8444102	9.405338
833	693889	578009537	28.8617394	9.409105
834	695556	580093704	28.8790582	9.412869
835	697225	582182875	28.8963666	9.416630
836	698896	584277056	28.9136646	9.420387
837	700569	586376253	28.9309523	9.424141
838	702244	588480472	28.9482297	9.427893
839	703921	590589719	28.9654967	9.431642
840	705600	592704000	28.9827535	9.435388
841	707281	594823321	29.0000000	9.439130
842	708964	596947688	29.0172363	9.442870
843	710649	599077107	29.0344623	9.446607
844	712336	601211584	29.0510781	9.450341
845	714025	603351125	29.0688837	9.454071
846	715716	605495736	29.0860791	9.457799
847	717409	607645423	29.1032644	9.461524
848	719104	609800192	29.1204396	9.465247
849	720801	611960049	29.1376046	9.468966
850	722500	614125000	29.1547565	9.472682

Numb.	Square.	Cube.	Square Root.	Cube Root.
851	724201	616295051	29·1719043	9·476395
852	725904	618470208	29·1890390	9·480106
853	727609	620650477	29·2061637	9·483813
854	729316	622835864	29·2232784	9·487518
855	731025	625026375	29·2403830	9·491219
856	732736	627222016	29·2574777	9·494918
857	734449	629422793	29·2745623	9·498614
858	736164	631628712	29·2916370	9·502307
859	737881	633839779	29·3087018	9·505998
860	739600	636056000	29·3257566	9·509685
861	741321	638277381	29·3428015	9·513369
862	743044	640503928	29·3598365	9·517051
863	744769	642735647	29·3768616	9·520730
864	746496	644972544	29·3938769	9·524406
865	748225	647214625	29·4108823	9·528079
866	749956	649461896	29·4278779	9·531749
867	751689	651714363	29·4448637	9·535417
868	753424	653972032	29·4618397	9·539081
869	755161	656234909	29·4788059	9·542743
870	756900	658503000	29·4957624	9·546402
871	758641	660776311	29·5127091	9·550058
872	760384	663054848	29·5296461	9·553712
873	762129	665338617	29·5465734	9·557363
874	763876	667627624	29·5634910	9·561010
875	765625	669921875	29·5803989	9·564655
876	767376	672221376	29·5972972	9·568297
877	769129	674526133	29·6141858	9·571937
878	770884	676836152	29·6310648	9·575574
879	772641	679151439	29·6479325	9·579208
880	774400	681472000	29·6647939	9·582839
881	776161	683797841	29·6816442	9·586468
882	777924	686128968	29·6984848	9·590093
883	779689	688465387	29·7153159	9·593716
884	781456	690807104	29·7321375	9·597337
885	783225	693154125	29·7489496	9·600954
886	784996	695506456	29·7657521	9·604569
887	786769	697864103	29·7825452	9·608181
888	788544	700227072	29·7993289	9·611791
889	790321	702595369	29·8161030	9·615397
890	792100	704969000	29·8328678	9·619001
891	793881	707347971	29·8496231	9·622603
892	795654	709732288	29·8663690	9·626201
893	797449	712121957	29·8831056	9·629797
894	799236	714516984	29·8998328	9·633390
895	801025	716917375	29·9165506	9·636951
896	802816	719323136	29·9332591	9·640569
897	804609	721734273	29·9499583	9·644154
898	806404	724150792	29·9666481	9·647736
899	808201	726572699	29·9833287	9·651316
900	810000	729000000	30·0000000	9·654893

## ARITHMETIC.

Numb.	Square.	Cube.	Square Root.	Cube Root.
901	811801	731432701	30.0166620	9.658468
902	813604	733870303	30.0333148	9.662040
903	815409	736314327	30.0499584	9.665609
904	817216	738763264	30.0665928	9.669176
905	819025	741217025	30.0832179	9.672740
906	820836	743677416	30.0998339	9.676301
907	822649	746142643	30.1164407	9.679860
908	824464	748613312	30.1330383	9.683416
909	826281	751089429	30.1496269	9.686970
910	828100	753571000	30.1662063	9.690521
911	829921	756058031	30.1827765	9.694069
912	831744	758550528	30.1993377	9.697615
913	833569	761048497	30.2158899	9.701158
914	835396	763551944	30.2324329	9.704696
915	837225	766060875	30.2489669	9.708236
916	839056	768575296	30.2654919	9.711772
917	840889	771095213	30.2820079	9.715305
918	842724	773620632	30.2985148	9.718835
919	844561	776151559	30.3150128	9.722363
920	846400	778688000	30.3315018	9.725886
921	848241	781223961	30.3479818	9.729410
922	850084	783777448	30.3644529	9.732930
923	851929	786330467	30.3809151	9.736448
924	853776	788889024	30.3973083	9.739963
925	855625	791453125	30.4136127	9.743475
926	857476	794022776	30.4302481	9.746985
927	859329	796597983	30.4466747	9.750493
928	861184	799178752	30.4630924	9.753998
929	863041	801765089	30.4795013	9.757500
930	864900	804357000	30.4959914	9.761000
931	866761	806954491	30.5122926	9.764497
932	868624	809557568	30.5286750	9.767992
933	870489	812166237	30.5450487	9.771484
934	872356	814780504	30.5614136	9.774974
935	874225	817400375	30.5777697	9.778461
936	876096	820025856	30.5941171	9.782946
937	877969	822656953	30.6104557	9.785428
938	879844	825293672	30.6267357	9.788908
939	881721	827936019	30.6431069	9.792386
940	883600	830584000	30.6594194	9.795861
941	885481	833237621	30.6757233	9.799323
942	887364	835896888	30.6920185	9.802803
943	889249	838561807	30.7083051	9.806271
944	891136	841232384	30.7245830	9.809736
945	893025	843908625	30.7408523	9.813198
946	894916	846590536	30.7571130	9.816659
947	896809	849278123	30.7733651	9.820117
948	898704	851971392	30.7896086	9.823572
949	900601	854670349	30.8058436	9.827025
950	902500	857375000	30.8220700	9.830475

Num. <sup>b</sup>	Square.	Cube.	Square Root.	Cube Root.
951	904401	850085351	30·8382879	9·833923
952	905304	862801408	30·8544972	9·837369
953	908209	865523177	30·8706931	9·840812
954	910116	868250664	30·8868904	9·844253
955	912025	870983875	30·9030743	9·847692
956	913936	873722816	30·9192497	9·851128
957	915849	876467493	30·9354166	9·854561
958	917764	879217912	30·9515751	9·857992
959	919681	881974079	30·9677251	9·861421
960	921600	884736000	30·9838668	9·864848
961	923521	887503681	31·0000000	9·868272
962	925444	890277128	31·0161248	9·871694
963	927369	893056347	31·0322413	9·875113
964	929296	895841344	31·0483494	9·878530
965	931225	898632125	31·0644491	9·881945
966	933156	901428696	31·0805405	9·885357
967	935089	904231063	31·0960236	9·888767
968	937024	907039232	31·1125984	9·892174
969	938961	909853209	31·1287648	9·895580
970	940900	912673000	31·1448230	9·898983
971	942841	915498611	31·1608729	9·902383
972	944784	918330048	31·1769145	9·905781
973	946729	921167317	31·1929479	9·909177
974	948676	924010424	31·2089731	9·912571
975	950625	926859375	31·2249900	9·915962
976	952576	929714176	31·2409987	9·919351
977	954529	932574833	31·2569992	9·922738
978	956484	935441352	31·2720915	9·926122
979	958441	938313739	31·2889757	9·929504
980	960400	941192001	31·3049517	9·932883
981	962361	944076141	31·3209195	9·936261
982	964324	946966168	31·3368792	9·939636
983	966289	949862087	31·3528308	9·943009
984	968256	952763994	31·3687743	9·946379
985	970225	955671625	31·3847097	9·949747
986	972196	958585256	31·4000369	9·953113
987	974169	961504803	31·4165561	9·956477
988	976144	964430272	31·4324673	9·959839
989	978121	967361669	31·4483704	9·963198
990	980100	970299000	31·4642654	9·966554
991	982081	973242271	31·4801525	9·969909
992	984064	976191488	31·4960315	9·973262
993	986049	979146657	31·5119025	9·976612
994	988036	982107784	31·5277655	9·979959
995	990025	985074875	31·5436206	9·983304
996	992016	988047936	31·5594677	9·986648
997	994009	991026973	31·5753068	9·989990
998	996004	994011992	31·5911380	9·993328
999	998001	997002999	31·6069613	9·996665

## OF RATIOS; PROPORTIONS, AND PROGRESSIONS.

NUMBERS are compared to each other in two different ways: the one comparison considers the difference of the two numbers, and is named Arithmetical Relation; and the difference sometimes the Arithmetical Ratio: the other considers their quotient, which is called Geometrical Relation; and the quotient the Geometrical Ratio. So, of these two numbers 6 and 3, the difference, or arithmetical ratio, is  $6 - 3$  or 3, but the geometrical ratio is  $\frac{6}{3}$  or 2.

There must be two numbers to form a comparison: the number which is compared, being placed first, is called the Antecedent; and that to which it is compared the Consequent. So, in the two numbers above, 6 is the antecedent, and 3 the consequent.

If two or more couplets of numbers have equal ratios, or equal differences, the equality is named Proportion, and the terms of the ratios Proportionals. So, the two couplets, 4, 2 and 8, 6, are arithmetical proportionals, because  $4 - 2 = 3 - 6 = 2$ ; and the two couplets 4, 2 and 6, 3, are geometrical proportionals, because  $\frac{4}{2} = \frac{6}{3} = 2$ , the same ratio.

To denote numbers as being geometrically proportional, a colon is set between the terms of each couplet, to denote their ratio; and a double colon, or else a mark of equality, between the couplets or ratios. So, the four proportionals, 4, 2, 6, 3 are set thus,  $4 : 2 :: 6 : 3$ , which means, that 4 is to 2 as 6 is to 3; or thus,  $4 : 2 = 6 : 3$ , or thus,  $\frac{4}{2} = \frac{6}{3}$ , both which mean, that the ratio of 4 to 2, is equal to the ratio of 6 to 3.

Proportion is distinguished into Continued and Discontinued. When the difference or ratio of the consequent of one couplet and the antecedent of the next couplet, is not the same as the common difference or ratio of the couplets, the proportion is discontinued. So, 4, 2, 8, 6 are in discontinued arithmetical proportion, because  $4 - 2 = 8 - 6 = 2$ , whereas  $8 - 2 = 6$ : and 4, 2, 6, 3 are in discontinued geometrical proportion, because  $\frac{4}{2} = \frac{6}{3} = 2$ , but  $\frac{6}{2} = 3$ , which is not the same.

But when the difference or ratio of every two succeeding terms is the same quantity, the proportion is said to be Continued, and the numbers themselves make a series of Continued Proportionals,

Proportionals, or a progression. So 2, 4, 6, 8 form an arithmetical progression, because  $4 - 2 = 6 - 4 = 8 - 6 = 2$ , all the same common difference; and 2, 4, 8, 16 a geometrical progression, because  $\frac{4}{2} = \frac{8}{4} = \frac{16}{8} = 2$ , all the same ratio.

When the following terms of a progression increase, or exceed each other, it is called an Ascending Progression or Series; but when the terms decrease, it is a descending one.

So, 0, 1, 2, 3, 4, &c. is an ascending arithmetical progression, but 9, 7, 5, 3, 1, &c. is a descending arithmetical progression, Also 1, 2, 4, 8, 16, &c. is an ascending geometrical progression, and 16, 8, 4, 2, 1, &c. is a descending geometrical progression.

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## ARITHMETICAL PROPORTION and PROGRESSION.

In Arithmetical Progression, the numbers or terms have all the same common difference.

The first and last terms of a Progression, are called the Extremes; and the other terms, lying between them, the Means.

The most useful part of arithmetical proportions, is contained in the following theorems:

**THEOREM 1.** If four quantities be in arithmetical proportion, the sum of the two extremes will be equal to the sum of the two means.

Thus, of the four 2, 4, 6, 8, here  $2 + 8 = 4 + 6 = 10$ .

**THEOREM 2.** In any continued arithmetical progression, the sum of the two extremes is equal to the sum of any two means that are equally distant from them, or equal to double the middle term when there is an uneven number of terms.

Thus, in the terms 1, 3, 5, it is  $1 + 5 = 3 + 3 = 6$ .

And in the series 2, 4, 6, 8, 10, 12, 14, it is  $2 + 14 = 4 + 12 = 6 + 10 = 8 + 8 = 16$ .

**THEOREM 3.** The difference between the extreme terms of an arithmetical progression, is equal to the common difference of the series multiplied by one less than the number of the terms.

So, of the ten terms, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, the common difference is 2, and one less than the number of terms 9; then the difference of the extremes is  $20 - 2 = 18$ , and  $2 \times 9 = 18$  also.

Consequently,

Consequently, the greatest term is equal to the least term added to the product of the common difference multiplied by 1 less than the number of terms.

**THEOREM 4.** The sum of all the terms, of any arithmetical progression, is equal to the sum of the two extremes multiplied by the number of terms, and divided by 2; or the sum of the two extremes multiplied by the number of the terms, gives double the sum of all the terms in the series.

This is made evident by setting the terms of the series in an inverted order, under the same series in a direct order, and adding the corresponding terms together in that order. Thus, in the series 1, 3, 5, 7, 9, 11, 13, 15; ditto inverted 15, 13, 11, 9, 7, 5, 3, 1; the sums are  $16 + 16 + 16 + 16 + 16 + 16 + 16 + 16$ , which must be double the sum of the single series, and is equal to the sum of the extremes repeated so often as are the number of the terms.

From these theorems may readily be found any one of these five parts; the two extremes, the number of terms, the common difference, and the sum of all the terms, when any three of them are given; as in the following problems:

#### PROBLEM I.

*Given the Extremes, and the Number of Terms; to find the Sum of all the Terms.*

#### RULE.

ADD the extremes together, multiply the sum by the number of terms, and divide by 2.

#### EXAMPLES.

1. The extremes being 3 and 19, and the number of terms 9; required the sum of the terms?

19

3

—

22

9

—

2 ) 198

Ansf. 99

$$\text{Or } \frac{19+3}{2} \times 9 = \frac{22}{2} \times 9 = 11 \times 9 = 99.$$

2. It is required to find the number of all the strokes a clock strikes in one whole revolution of the index, or in 12 hours?

Ansf. 78.  
Ex.

Ex. 3. How many strokes do the clocks of Venice strike in the compass of the day, which go right on from 1 to 24 o'clock?

Anf. 300.

4. What debt can be discharged in a year, by weekly payments in arithmetical progression, the first payment being 1*s*, and the last or 52d payment 5*l 3s*?

Anf. 135*l 4s*.

### PROBLEM II.

*Given the Extremes, and the Number of Terms; to find the Common Difference.*

#### RULE.

SUBTRACT the less extreme from the greater, and divide the remainder by 1 less than the number of terms, for the common difference.

#### EXAMPLES.

1. The extremes being 3 and 19, and the number of terms 9; required the common difference?

$$\begin{array}{r} 19 \\ - 3 \\ \hline 16 \\ 8 ) \underline{16} \\ \hline 2 \end{array} \quad \text{Or } \frac{19 - 3}{9 - 1} = \frac{16}{8} = 2.$$

2. If the extremes be 10 and 70, and the number of terms 21; what is the common difference, and the sum of the series?

Anf. The com. diff. is 3, and the sum is 840.

3. A certain debt can be discharged in one year, by weekly payments in arithmetical progression, the first payment being 1*s*, and the last 5*l 3s*; what is the common difference of the terms?

Anf. 2.

### PROBLEM III.

*Given one of the Extremes, the Common Difference, and the Number of Terms; to find the other Extreme, and the Sum of the Series.*

#### RULE.

MULTIPLY the common difference by 1 less than the number of terms, and the product will be the difference of the extremes: Therefore add the product to the less extreme, to give the greater; or subtract it from the greater, to give the less.

## EXAMPLES.

1. Given the least term 3, the common difference 2, of an arithmetical series of 9 terms; to find the greatest term, and the sum of the series.

$$\begin{array}{r}
 2 \\
 8 \\
 \hline
 16 \\
 3 \\
 \hline
 19 \text{ the greatest term} \\
 3 \text{ the least} \\
 \hline
 22 \text{ sum} \\
 9 \text{ number of terms.} \\
 \hline
 2) \overline{198} \\
 99 \text{ the sum of the series.}
 \end{array}$$

2. If the greatest term be 70, the common difference 3, and the number of terms 21; what is the least term and the sum of the series?

Anf. The least term is 10, and the sum is 840.

3. A debt can be discharged in a year, by paying 1 shilling the first week, 3 shillings the second, and so on, always 2 shillings more every week; what is the debt, and what will the last payment be?

Anf. The last payment will be 5*l* 3*s*, and the debt is 135*l* 4*s*.

## PROBLEM IV.

*To find an Arithmetical Mean Proportional between Two Given Terms.*

## RULE.

ADD the two given extremes or terms together, and take half their sum for the arithmetical mean required.

## EXAMPLE.

To find an arithmetical mean between the two numbers 4 and 14.

$$\begin{array}{ccc}
 \text{Here} & \text{Or} & \text{Or} \\
 14 & 4 & 5 \\
 4 & \hline
 2) \overline{18} & 5 & 9 \\
 \text{Anf.} \quad \underline{9} & \underline{4} & \underline{9}
 \end{array}$$

the com dif.  
the less extreme.

So that 9 is the mean required, by both methods.

## PROBLEM

## PROBLEM V.

*To find Two Arithmetical Means between Two Given Extremes.*

## RULE.

SUBTRACT the less extreme from the greater, and divide the difference by 3, so will the quotient be the common difference; which being continually added to the less extreme, or taken from the greater, gives the means.

## EXAMPLE.

To find two arithmetical means between 2 and 8.

Here 8

$$\begin{array}{r} 2 \\ 3 ) \underline{6} \\ \text{com. dif. } 2 \end{array} \quad \begin{array}{l} \text{Then } 2 + 2 = 4 \text{ the one mean,} \\ \text{and } 4 + 2 = 6 \text{ the other mean.} \end{array}$$

## PROBLEM VI.

*To find any Number of Arithmetical Means between Two Given Terms or Extremes.*

## RULE.

SUBTRACT the less extreme from the greater, and divide the difference by 1 more than the number of means required to be found, which will give the common difference; then this being added continually to the least term, or subtracted from the greatest, will give the mean terms required.

## EXAMPLE.

To find five arithmetical means between 2 and 14.

Here 14

$$\begin{array}{r} 2 \\ 6 ) \underline{12} \\ \text{com. dif. } 2 \end{array} \quad \begin{array}{l} \text{Then by adding this com. dif. continually,} \\ \text{the means are found } 4, 6, 8, 10, 12. \end{array}$$

See more of Arithmetical progression in the Algebra.

GEOMETRICAL PROPORTION *and* PROGRESSION.

IN Geometrical Progression the numbers or terms have all the same multiplier or divisor.

The most useful part of Geometrical Proportion, is contained in the following theorems.

**THEOREM 1.** If four quantities be in geometrical proportion, the product of the two extremes will be equal to the product of the two means.

Thus, in the four 2, 4, 3, 6, it is  $2 \times 6 = 3 \times 4 = 12$ .

And hence, if the product of the two means be divided by one of the extremes, the quotient will give the other extreme. So, of the above numbers, the product of the means  $12 \div 2 = 6$  the one extreme, and  $12 \div 6 = 2$  the other extreme; and this is the foundation and reason of the practice in the Rule of Three.

**THEOREM 2.** In any continued geometrical progression, the product of the two extremes is equal to the product of any two means that are equally distant from them, or equal to the square of the middle term when there is an uneven number of terms.

Thus, in the terms 2, 4, 8, it is  $2 \times 8 = 4 \times 4 = 16$ .

And in the series 2, 4, 8, 16, 32, 64, 128,

it is  $2 \times 128 = 4 \times 64 = 8 \times 32 = 16 \times 16 = 256$ .

**THEOREM 3.** The quotient of the extreme terms of a geometrical progression, is equal to the common ratio of the series raised to the power denoted by 1 less than the number of the terms.

Consequently the greatest term is equal to the least term multiplied by the said quotient.

So, of the ten terms 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, the common ratio is 2, one less than the number of terms 9; then the quotient of the extremes is  $\frac{1024}{2} = 512$ , and  $2^9 = 512$  also.

**THEOREM**

**THEOREM 4.** The sum of all the terms, of any geometrical progression, is found by adding the greatest term to the difference of the extremes divided by 1 less than the ratio.

So, the sum of 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024.

(whose ratio is 2), is  $1024 + \frac{1024 - 2}{2 - 1} = 1024 + 1022 = 2046$ .

The foregoing, and several other properties of geometrical proportion, are demonstrated more at large in the Algebraic part of this work. A few examples may here be added of the theorems, just delivered, with some problems concerning mean proportionals.

#### EXAMPLES.

1. The least of ten terms, in geometrical progression, being 1, and the ratio 2; what is the greatest term, and the sum of all the terms?

Anf. The greatest term is 512, and the sum 1023.

2. What debt may be discharged in a year, or 12 months, by paying 1*l* the first month, 2*l* the second, 4*l* the third, and so on, each succeeding payment being double the last; and what will the last payment be?

Anf. The debt 4095*l*, and the last payment 2048*l*.

#### PROBLEM I.

*To find One Mean Geometrical Proportional between any Two Numbers.*

#### RULE.

MULTIPLY the two numbers together, and extract the square root of the product, which will give the mean proportional sought.

#### EXAMPLE.

To find a geometrical mean between the two numbers 3 and 12.

*First Way.*

$$\begin{array}{r} 12 \\ \times 3 \\ \hline 36 \end{array} \quad (6 \text{ the mean.})$$

## PROBLEM II.

*To find Two Geometrical Mean Proportionals between any Two Numbers.*

## RULE.

DIVIDE the greater number by the less, and extract the cube root of the quotient, which will give the common ratio of the terms. Then multiply the least given term by the ratio for the first mean, and this mean again by the ratio for the second mean: or, divide the greater of the two-given terms by the ratio for the greater mean, and divide this again by the ratio for the less mean.

## EXAMPLE.

To find two geometrical mean proportionals between 3 and 24.

Here  $3 \sqrt[3]{24} = 8$ ; its cube root 2 is the ratio.

Then  $3 \times 2 = 6$ , and  $6 \times 2 = 12$ , the two means.

Or  $24 \div 2 = 12$ , and  $12 \div 2 = 6$ , the same.

That is, the two means between 3 and 24, are 6 and 12.

## PROBLEM III.

*To find any Number of Geometrical Mean Proportionals between Two Numbers.*

## RULE.

DIVIDE the greater number by the less, and extract such root of the quotient whose index is 1 more than the number of means required; that is, the 2d root for one mean, the 3d root for two means, the 4th root for three means, and so on; and that root will be the common ratio of all the terms. Then, with the ratio multiply continually from the first term, or divide continually from the last or greatest term.

## EXAMPLE.

To find four geometrical mean proportionals between 3 and 96.

Here  $3 \sqrt[5]{96} = 32$ ; the 5th root of which is 2, the ratio.

Then  $3 \times 2 = 6$ , &  $6 \times 2 = 12$ , &  $12 \times 2 = 24$ , &  $24 \times 2 = 48$ .

Or  $96 \div 2 = 48$ , &  $48 \div 2 = 24$ , &  $24 \div 2 = 12$ , &  $12 \div 2 = 6$ .

That is 6, 12, 24, 48, are the four means between 3 and 96,

## OF MUSICAL PROPORTION.

THERE is also a third kind of proportion, called Musical, which being but of little or no common use, a very short account of it may here suffice.

Musical Proportion is when, of three numbers, the first has the same proportion to the third, as the difference between the first and second, hath to the difference between the second and third.

As in these three, 6, 8, 12;

where  $6 : 12 :: 8 - 6 : 12 - 8$ ,

that is  $6 : 12 :: 2 : 4$ .

When four numbers are in musical proportion; then the first has the same proportion to the fourth, as the difference between the first and second hath to the difference between the third and fourth.

As in these, 6, 8, 12, 18;

where  $6 : 18 :: 8 - 6 : 18 - 12$ ,

that is  $6 : 18 :: 2 : 6$ .

When numbers are in musical progression, their reciprocals are in arithmetical progression; and the converse, that is, when numbers are in arithmetical progression, their reciprocals are in musical progression.

So in these musicals 6, 8, 12, their reciprocals  $\frac{1}{6}, \frac{1}{8}, \frac{1}{12}$ , are in arithmetical progression; for  $\frac{1}{6} + \frac{1}{12} = \frac{3}{12} = \frac{1}{4}$ ; and  $\frac{1}{8} + \frac{1}{12} = \frac{2}{8} = \frac{1}{4}$ ; that is, the sum of the extremes is equal to double the mean, which is the property of arithmeticals.

The method of finding out numbers in musical proportion, is best expressed by letters in Algebra.

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FELLOWSHIP, OR PARTNERSHIP.

FELLOWSHIP is a rule, by which any sum or quantity may be divided into any number of parts, which shall be in any given proportion to one another.

By this rule are adjusted the gains or loss or charges of partners

partners in company; or the effects of bankrupts, or legacies in case of a deficiency of assets or effects; or the shares of prizes; or the numbers of men to form certain detachments; or the division of waste lands among a number of proprietors.

Fellowship is either Single or Double. It is Single, when the shares or portions are to be proportional each to one single given number only; as when the stocks of partners are all employed for the same time: And Double, when each portion is to be proportional to two or more numbers; as when the stocks of partners are employed for different times.

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## SINGLE FELLOWSHIP.

### GENERAL RULE.

**A**DD together the numbers that denote the proportion of the shares. Then say,

As the sum of the said proportional numbers,  
Is to the whole sum to be parted or divided,  
So is each several proportional number,  
To the corresponding share or part.

**O**r, As the whole stock, is to the whole gain or loss,  
So is each man's particular stock,  
To his particular share of the gain or loss.

**T**O PROVE THE WORK. Add all the shares or parts together, and the sum will be equal to the whole number to be shared, when the work is right.

### EXAMPLES.

1. To divide the number 240 into three such parts, as shall be in proportion to each other as the three numbers 1, 2, and 3.

Here  $1 + 2 + 3 = 6$ , the sum of the numbers.

Then, as  $6 : 240 :: 1 : 40$  the 1st part,  
and as  $6 : 240 :: 2 : 80$  the 2d part,  
also as  $6 : 240 :: 3 : 120$  the 3d part,

Sum of all 240, the proof.

**Ex. 2.** Three persons, A, B, C, freighted a ship with 340 tuns of wine ; of which, A loaded 110 tuns, B 97, and C the rest : in a storm the seamen were obliged to throw overboard 85 tuns ; how much must each person sustain of the loss ?

Here  $110 + 97 = 207$  tuns, loaded by A and B ;  
therefore  $340 - 207 = 133$  tuns, loaded by C.

Hence, as  $340 : 85 :: 110$

or as  $4 : 1 :: 110 : 27\frac{1}{2}$  tuns = A's loss ;

and as  $4 : 1 :: 97 : 24\frac{1}{4}$  tuns = B's loss ;

also as  $4 : 1 :: 133 : 33\frac{1}{4}$  tuns = C's loss ;

Sum 85 tuns, the proof.

**3.** Two merchants, C and D, made a stock of  $120l$ ; of which C contributed  $75l$ , and D the rest : by trading they gained  $30l$ ; what must each have of it ?

Anf. C  $18l 15s$ , and D  $11l 5s$ .

**4.** Three merchants, E, F, G, make a stock of  $700l$ , of which E contributed  $123l$ , F  $358l$ , and G the rest : by trading they gain  $125l 10s$ ; what must each have of it ?

Anf. E must have  $22l 1s 0d 2\frac{2}{3}q$ .

F - - -  $64 3 8 0\frac{3}{5}q$ .

G - - -  $39 5 3 1\frac{1}{3}q$ .

**5.** A General imposing a contribution \* of  $700l$  on four villages, to be paid in proportion to the number of inhabitants contained in each ; the 1st containing 250, the 2d 350, the 3d 400, and the 4th 500 persons ; what part must each village pay ?

Anf. the 1st to pay  $116l 13s 4d$ .

the 2d - -  $163 6 8$

the 3d - -  $186 13 4$

the 4th - -  $233 6 8$

**6.** A piece of ground, consisting of  $37 \text{ ac } 2 \text{ ro } 14 \text{ ps}$ , is to be divided among three persons, L, M, and N, in proportion to their estates : now if L's estate be worth  $500l$  a year, M's  $320l$ , and N's  $75l$ ; what quantity of land must each one have ?

Anf. L must have  $20 \text{ ac } 3 \text{ ro } 39\frac{1}{7}\frac{9}{9}ps$ .

M - - -  $13 1 30\frac{4}{7}\frac{6}{9}$ .

N - - -  $3 0 23\frac{1}{7}\frac{3}{9}$ .

**7.** A person is indebted to O  $57l 15s$ , to P  $108l 3s 8d$ , to Q  $22l 10d$ , and to R  $73l$ ; but at his decease, his effects

\* Contribution is a tax paid by provinces, towns, villages, &c. to excuse them from being plundered. It is paid in provisions or in money, and sometimes in both.

are found to be worth no more than  $170l\ 14s$ : how must it be divided among his creditors?

Anf. o must have  $37l\ 15s\ 5d\ 2\frac{5302}{10439}q.$

P	-	-	70	15	2	$2\frac{7498}{10439}$
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Q	-	-	14	8	4	$0\frac{4720}{10439}$
---	---	---	----	---	---	-----------------------

R	-	-	47	14	11	$2\frac{3358}{10439}$
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Ex. 8. A ship, worth  $900l$ , being entirely lost, of which  $\frac{1}{8}$  belonged to s,  $\frac{1}{4}$  to t, and the rest to v; what loss will each sustain, supposing  $540l$  of her were infured?

Anf. s will lose  $45l$ , t  $90l$ , and v  $225l$ .

9. Four persons, w, x, y, and z, spent among them  $25s$ , and agree that w shall pay  $\frac{1}{2}$  of it, x  $\frac{1}{3}$ , y  $\frac{1}{4}$ , and z  $\frac{1}{5}$ ; that is, their shares are to be in proportion as  $\frac{1}{2}$ ,  $\frac{1}{3}$ ,  $\frac{1}{4}$ , and  $\frac{1}{5}$ : what are their shares?

Anf. w must pay  $9s\ 8d\ 3\frac{41}{7}q.$

x	-	-	6	5	$3\frac{53}{77}$
---	---	---	---	---	------------------

y	-	-	4	10	$1\frac{59}{77}$
---	---	---	---	----	------------------

z	-	-	3	10	$3\frac{1}{77}$
---	---	---	---	----	-----------------

10. A detachment, consisting of 5 companies, being sent into a garrison, in which the duty required 76 men a day; what number of men must be furnished by each company, in proportion to their strength; the 1st consisting of 54 men, the 2d of 51 men, the 3d of 48 men, the 4th of 39, and the 5th of 36 men?

Anf. The 1st must furnish 18, the 2d 17, the 3d 16, the 4th 13, and the 5th 12 men\*.

## DOUBLE FELLOWSHIP.

DOUBLE FELLOWSHIP, as has been said, is concerned in cases in which the stocks of partners are employed or continued for different times,

\* Questions of this nature frequently occurring in military service, General Haviland, an officer of great merit, contrived an ingenious instrument, for more expeditiously resolving them; which is distinguished by the name of the inventor, being called a Haviland.

## RULE\*.

MULTIPLY each person's stock by the time of its continuance ; then divide the quantity, as in Single Fellowship, into shares in proportion to these products, by saying,

As the total sum of all the said products,  
Is to the whole gain or loss, or quantity to be parted,  
So is each particular product,  
To the correspondent share of the gain or loss.

## EXAMPLES.

1. A had in company  $50l$  for 4 months, and B had  $60l$  for 5 months ; at the end of which they find  $24l$  gained : how must it be divided between them ?

$$\begin{array}{r} \text{Here } 50 \quad 60 \\ \quad 4 \quad 5 \\ \hline 200 + 300 = 500 \end{array}$$

Then, as  $500 : 24 :: 200 : 9\frac{3}{5} = 9l\ 12s = A$ 's share.  
and as  $500 : 24 :: 300 : 14\frac{2}{5} = 14\ 8 = B$ 's share.

2. C and D hold a piece of ground in common, for which they are to pay  $36l$ . C put in 23 horses for 27 days, and D 21 horses for 39 days ; how much ought each man to pay of the rent ?

Anf. C must pay  $15l\ 10s\ 6d$ .  
D must pay  $20\ 9\ 6$ .

3. Three persons, E, F, G, hold a pasture in common, for which they are to pay  $30l$  per annum ; into which E put 7 oxen for 3 months, F put 9 oxen for 5 months, and G put in 4 oxen for 12 months ; how much must each person pay of the rent ?

Anf. E must pay  $5l\ 10s\ 6d\ 1\frac{5}{19}q.$   
F - -  $11\ 16\ 10\ 0\frac{3}{19}.$   
G - -  $12\ 12\ 7\ 2\frac{6}{19}.$

4. A ship's company take a prize of  $1000l$ , which they agree to divide among them according to their pay and the time they have been on board : now the officers and midshipmen have been on board 6 months, and the sailors 3 months ;

\* The proof of this rule is as follows : When the times are equal, the shares of the gain or loss are evidently as the stocks, as in Single Fellowship ; and when the stocks are equal, the shares are as the times ; therefore, when neither are equal, the shares must be as their products.

the officers have 40*s* a month, the midshipmen 30*s*, and the sailors 22*s* a month; moreover, there are 4 officers, 12 midshipmen, and 110 sailors: what will each man's share be?

Anf. each officer must have 23*l* 2*s* 5*d* 0*9*<sup>2</sup><sub>7</sub><sub>3</sub>*q*.

each midship. - - 17 6 9 3*6*<sup>9</sup><sub>17</sub><sub>3</sub>*q*.

each seaman - - 6 7 2 0*8*<sub>17</sub><sub>3</sub>*q*.

Ex. 5. H, with a capital of 1000*l*, began trade the first of January, and, meeting with success in business, took in I as a partner, with a capital of 1500*l*, on the first of March following. Three months after that they admit K as a third partner, who brought into stock 2800*l*. After trading together till the end of the year, they find there has been gained 1776*l* 10*s*: how must this be divided among the partners?

Anf. H must have 457*l* 9*s* 4<sup>1</sup><sub>4</sub>*d*.

I - - 571 16 8<sup>1</sup><sub>4</sub>.

K - - 747 3 11<sup>1</sup><sub>4</sub>.

6. x, y, and z made a joint-stock for 12 months; x at first put in 20*l*, and 4 months after 20*l* more; y put in at first 30*l*, at the end of 3 months he put in 20*l* more, and 2 months after he put in 40*l* more; z put in at first 60*l*, and 5 months after he put in 10*l* more, 1 month after which he took out 30*l*; during the 12 months they gained 50*l*; how much of it must each have?

Anf. x must have 10*l* 18*s* 6*d* 3<sup>4</sup><sub>6</sub><sub>1</sub>*q*.

y - - 22 8 1 0<sup>1</sup><sub>6</sub><sub>1</sub>*q*.

z - - 16 13 4 0.

### SIMPLE INTEREST.

**INTEREST** is the premium or sum allowed for the loan, or forbearance, of money.

The money lent, or forborne, is called the Principal.

The sum of the principal and its interest, added together, is called the Amount.

Interest is allowed at so much per cent. per annum; which premium per cent. per annum, or interest of 100*l* for a year, is called the rate of Interest:—So,

When

When interest is at 3 per cent. the rate is 3;  
 - - - - 4 per cent. - - 4;  
 - - - - 5 per cent. - - 5;  
 - - - - 6 per cent. - - 6.

But, by law, interest ought not to be taken higher than at the rate of 5 per cent.

Interest is of two sorts; Simple and Compound.

Simple Interest is that which is allowed for the principal lent or forborn only, for the whole time of forbearance.

As the interest of any sum, for any time, is directly proportional to the principal sum, and also to the time of continuance; hence arises the following general rule of calculation.

#### GENERAL RULE.

As  $100l$  is to the rate of interest, so is any given principal to its interest for one year. And again,

As 1 year is to any given time, so is the interest for a year, just found, to the interest of the given sum for that time.

OTHERWISE. Take the interest of 1 pound for a year, which multiply by the given principal, and this product again by the time of loan or forbearance, in years and parts, for the interest of the proposed sum for that time.

*Note*, When there are certain parts of years in the time, as quarters, or months, or days; they may be worked for, either by taking the aliquot or like parts of the interest of a year, or by the Rule of Three, in the usual way. Also, to divide by 100, is done by only pointing off two figures for decimals.

#### EXAMPLES.

1. To find the interest of  $230l\ 10s$ , for 1 year, at the rate of 4 per cent. per annum.

Here, As  $100 : 4 :: 230l\ 10s : 9l\ 4s\ 4\frac{3}{4}d$ .

$$\begin{array}{r}
 & & 4 \\
 & 100) & 9,22 & 0 \\
 & & 20 \\
 & & \hline
 & & 4,40 \\
 & & 12 \\
 & & \hline
 & & 4,80 \\
 & & 4 \\
 & & \hline
 & & 3,20
 \end{array}
 \qquad \text{Ans. } 9l\ 4s\ 4\frac{3}{4}d.$$

Ex. 2.

**Ex. 2.** To find the interest of  $547l\ 15s$ , for 3 years, at 5 per cent. per annum.

$$\text{As } 100 : 5 :: 547.75 :$$

$$\text{Or } 20 : 1 :: 547.75 : 27.3875 \text{ interest for 1 year.}$$

$$\begin{array}{r} 3 \\ l \ 82.1625 \text{ ditto for 3 years.} \\ \hline 20 \\ s \ 3.2500 \\ \hline 12 \\ d \ \underline{3.00} \end{array}$$

Anf.  $82l\ 3s\ 3d.$

**3.** To find the interest of 200 guineas, for 4 years 7 months and 25 days, at  $4\frac{1}{2}$  per cent. per annum.

$$\begin{array}{r} \text{ds} & l & \text{ds} \\ 210l & \text{As } 365 : 9.45 :: 25 : l \\ \hline 4\frac{1}{2} & \text{or } 73 : 9.45 :: 5 : .6472 \\ 840 & & 5 \\ 105 & & 73) \ 47.25 (.6472 \\ \hline 9.45 \text{ interest for 1 yr.} & 345 \\ 4 & 530 \\ \hline 37.80 & 19 \\ \hline 6 \text{ mo} = \frac{1}{2} 4.725 & \text{ditto 4 years.} \\ 1 \text{ mo} = \frac{1}{6} .7875 & \text{ditto 1 month.} \\ .6472 & \text{ditto 25 days.} \\ \hline l \ 43.9597 & \\ \hline 20 & \\ \hline s \ 19.1940 & \\ \hline 12 & \\ \hline d \ 2.3280 & \text{Anf. } 43l\ 19s\ 2\frac{3}{4}d. \\ \hline 4 & \\ \hline q \ 1.3120 & \end{array}$$

**4.** To find the interest of  $450l$ , for a year, at 5 per cent. per annum. Anf.  $22l\ 10s.$

**5.** To find the interest of  $715l\ 12s\ 6d$ , for a year, at  $4\frac{1}{2}$  per cent. per annum. Anf.  $32l\ 4s\ 0\frac{3}{4}d.$

**6.** To find the interest of  $720l$ , for 3 years, at 5 per cent. per annum. Anf.  $108l.$

**7.** To find the interest of  $355l\ 15s$ , for 4 years, at 4 per cent. per annum. Anf.  $56l\ 18s\ 4\frac{3}{4}d.$

**8.** To find the interest of  $32l\ 5s\ 8d$ , for 7 years, at  $4\frac{1}{4}$  per cent. per annum. Anf.  $9l\ 12s\ 1d.$

**9.** To find the interest of  $170l$ , for  $1\frac{1}{2}$  year, at 5 per cent. per annum. Anf.  $12l\ 15s.$

Ex. 10.

- Ex. 10. To find the insurance on  $205l\ 15s$ , for  $\frac{1}{4}$  of a year,  
 $\frac{1}{4}$  per cent. per annum. Anf.  $2l\ 1s\ 1\frac{3}{4}d.$
11. To find the interest of  $319l\ 6d$ , for  $5\frac{3}{4}$  years, at  $3\frac{3}{4}$  per  
cent. per annum. Anf.  $68l\ 15s\ 9\frac{1}{2}d.$
12. To find the insurance on  $107l$ , for 117 days, at  $4\frac{3}{4}$  per  
cent. per annum. Anf.  $1l\ 12s\ 7d.$
13. To find the interest of  $17l\ 5s$ , for 117 days, at  $4\frac{3}{4}$  per  
cent. per annum. Anf.  $5s\ 3d.$
14. To find the insurance on  $712l\ 6s$ , for 8 months, at  
 $7\frac{1}{2}$  per cent. per annum. Anf.  $35l\ 12s\ 3\frac{1}{2}d.$

*Note.* The Rules for Simple Interest, serve also to calculate Insurances, or the Purchase of Stocks, or any thing else that is rated at so much per cent.

See also more on the subject of Interest, with the algebraical expression and investigation of the rules, at the end of the Algebra, next following.

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## COMPOUND INTEREST.

**C**OUPOND **I**NTEREST, called also Interest upon Interest, is that which arises from the principal and interest, taken together, as it becomes due, at the end of each stated time of payment.

Although it be not lawful to lend money at Compound Interest, yet in purchasing annuities, pensions, or leases in reversion, it is usual to allow Compound Interest to the purchaser for his ready money.

### RULES.

1. **FIND** the amount of the given principal, for the time of the first payment, by Simple Interest. Then consider this amount as a new principal for the second payment, whose amount calculate as before. And so on through all the payments to the last, always accounting the last amount as a new principal for the next payment. The reason of which is evident from the definition of Compound Interest. *Or else,*

2. Find the amount of 1 pound for the time of the first payment, and raise or involve it to the power whose index is denoted by the number of payments. Then that power multiplied by the given principal, will produce the whole amount.

amount. From which the said principal being subtracted, leaves the Compound Interest of the same. As is evident from the first Rule.

## EXAMPLES.

1. To find the amount of  $720l$ , for 4 years, at 5 per cent. per annum.

Here 5 is the 20th part of 100, and the interest of  $1l$  for a year is  $\frac{1}{20}$  or  $.05$ , and its amount  $1.05$ . Therefore,

1. By the 1st Rule.

$l$	$s$	$d$	
20)	720	0	0
	36	0	0

1st yr's princip.  
1st yr's interest.

2. By the 2d Rule.

$1.05$  amount of  $1l$ .

20)	720	0	0	1st yr's princip.	$1.05$	
	36	0	0	1st yr's interest.	<u>—</u>	$1.1025$ 2d power of it.
20)	756	0	0	2d yr's princip.	$1.1025$ ditto.	
	37	16	0	2d yr's interest.	<u>—</u>	$1.21550625$ 4th pow. of it.
20)	793	16	0	3d yr's princip.	$720$	
	39	13	$9\frac{1}{2}$	3d yr's interest.	<u>—</u>	
	<u>—</u>	<u>—</u>			$l\ 875.1645$	
20)	833	9	$9\frac{1}{2}$	4th yr's princip.	$20$	
	41	13	$5\frac{3}{4}$	4th yr's interest.	<u>—</u>	$s\ 3.2900$
	<u>—</u>	<u>—</u>			<u>—</u>	
	$\underline{\underline{L}}\ 875$	$\underline{\underline{3}}$	$\underline{\underline{3\frac{1}{4}}}$	the whole amo <sup>t</sup> .	$12$	
				or ans. required.	<u>—</u>	
					$d\ 3.4800$	<u>—</u>

2. To find the amount of  $50l$ , in 5 years, at 5 per cent. per annum, compound interest. Anf.  $63l. 16s 3\frac{1}{4}d$ .

3. To find the amount of  $50l$ , in 5 years, or 10 half-years, at 5 per cent. per annum, compound interest, the interest payable half-yearly. Anf.  $64l 0s 1d$ .

4. To find the amount of  $50l$ , in 5 years, or 20 quarters, at 5 per cent. per annum, compound interest, the interest payable quarterly. Anf.  $64l 2s 0\frac{1}{4}d$ .

5. To find the compound interest of  $370l$ , forborn for 6 years, at 4 per cent. per annum. Anf.  $98l 3s 4\frac{1}{4}d$ .

6. To find the compound interest of  $410l$ , forborn for  $2\frac{1}{2}$  years, at  $4\frac{1}{2}$  per cent. per annum, the interest payable half-yearly. Anf.  $48l 4s 11\frac{1}{4}d$ .

7. To find the amount, at compound interest, of  $217l$ , forborn for  $2\frac{1}{2}$  years, at 5 per cent. per annum, the interest payable quarterly. Anf.  $242l 13s 4\frac{1}{2}d$ .

*Note.* See the Rules for Compound Interest algebraically investigated, at the end of the Algebra.

## ALLIGATION.

**ALLIGATION** teaches how to compound or mix together several simples of different qualities, so that the composition may be of some intermediate quality, or rate. It is commonly distinguished into two cases, Alligation Medial, and Alligation Alternate.

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## ALLIGATION MEDIAL.

**ALLIGATION MEDIAL** is the method of finding the rate or quality of the composition, from having the quantities and rates or qualities of the several simples given.

## RULE \*.

MULTIPLY the quantity of each ingredient by its rate or quality; then add all the products together, and add also all

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\* *Demonstration.* The Rule is thus proved by Algebra.

Let  $a, b, c$  be the quantities of the ingredients, and  $m, n, p$  their rates, or qualities, or prices; then  $am, bn, cp$  are their several values, and  $am + bn + cp$  the sum of their values, also  $a + b + c$  is the sum of the quantities, and if  $r$  denote the rate of the whole composition, then  $\underline{a + b + c \times r}$  will be the value of the whole, conseq.  $\underline{a + b + c \times r} = \underline{am + bn + cp}$ , and  $r = am + bn + cp \div a + b + c$ , which is the Rule.

*Note.* If an ounce or any other quantity of pure gold be reduced into 24 equal parts, these parts are called Caracts; but gold is often mixed with some base metal, which is called the Alloy, and the mixture is said to be of so many caracts fine, according to the proportion of pure gold contained in it; thus, if 22 caracts of pure gold, and 2 of alloy be mixed together, it is said to be 22 caracts fine.

If any one of the simples be of little or no value with respect to the rest, its rate is supposed to be nothing; as water mixed with wine, and alloy with gold and silver.

the quantities together into another sum: then divide the former sum by the latter, that is, the sum of the products by the sum of the quantities, and the quotient will be the rate or quality of the composition required.

## EXAMPLES.

1. If three sorts of gunpowder be mixed together, viz., 50lb at 12d a pound, 44lb at 9d, and 26lb at 8d a pound; how much a pound is the composition worth?

Here 50, 44, 26 are the quantities,  
and 12, 9, 8 the rates or qualities;  
then  $50 \times 12 = 600$   
 $44 \times 9 = 396$   
 $26 \times 8 = 208$

$$\begin{array}{r} 120 ) \\ 1204 \\ \hline 4 \end{array} \quad ( 10 \frac{4}{120} = 10 \frac{1}{30}$$

Anf. The rate or price is  $10 \frac{1}{30}$ d the pound.

2. A composition being made of 5lb of tea at 7s per lb, 9lb at 8s 6d per lb, and  $14\frac{1}{2}$ lb at 5s 10d per lb; what is a lb of it worth? Anf. 6s  $10\frac{1}{2}$ d.

3. Mixed 4 gallons of wine at 4s 10d per gall, with 7 gallons at 5s 3d per gall, and  $9\frac{3}{4}$  gallons at 5s 8d per gall; what is a gallon of this composition worth? Anf. 5s  $4\frac{1}{4}$ d.

4. A mealman would mix 3 bushels of flour at 3s 5d per bushel, 4 bushels at 5s 6d per bushel, and 5 bushels at 4s 8d per bushel: what is the worth of a bushel of this mixture? Anf. 4s  $7\frac{1}{2}$ d.

5. A farmer mixes 20 bushels of wheat at 5s the bushel, with 36 bushels of rye at 3s the bushel, and 40 bushels of barley at 2s per bushel: how much is a bushel of the mixture worth? Anf. 3s.

6. Having melted together 7 oz of gold of 22 caracts fine,  $12\frac{1}{2}$  oz of 21 caracts fine, and 17 oz of 19 caracts fine: I would know the fineness of the composition? Anf.  $20\frac{1}{73}$  caracts fine.

7. Of what fineness is that composition, which is made by mixing 3lb of silver of 9 oz fine, with 5lb 8oz of 10oz fine, and 1lb 10oz of alloy. Anf.  $7\frac{6}{43}$  oz fine.

## ALLIGATION ALTERNATE.

ALLIGATION ALTERNATE is the method of finding what quantity of any number of simples, whose rates are given, will compose a mixture of a given rate. So that it is the reverse of Alligation Medial, and may be proved by it.

## RULE I \*.

1. SET the rates of the simples in a column under each other.
  2. Connect, or link with a continued line, the rate of each simple, which is less than that of the compound, with one, or any number, of those that are greater than the compound; and each greater rate with one or any number of the less.
  3. Write the difference between the mixture rate, and that of each of the simples, opposite the rate with which they are linked.
  4. Then if only one difference stand against any rate, it will be the quantity belonging to that rate; but if there be several, their sum will be the quantity.
- 

\* *Demonst.* By connecting the less rate to the greater, and placing the difference between them and the rate alternately, the quantities resulting are such, that there is precisely as much gained by one quantity as is lost by the other, and therefore the gain and loss upon the whole is equal, and is exactly the proposed rate: and the same will be true of any other two simples managed according to the Rule.

In like manner, let the number of simples be what they will, and with how many soever every one is linked, since it is always a less with a greater than the mean price, there will be an equal balance of loss and gain between every two, and consequently an equal balance on the whole. Q. E. D.

It is obvious, from the Rule, that questions of this sort admit of a great variety of answers; for, having found one answer, we may find as many more as we please, by only multiplying or dividing each of the quantities found, by 2, or 3, or 4, &c.: the reason of which is evident; for, if two quantities, of two simples, make a balance of loss and gain, with respect to the mean price, so must also the double or treble, the  $\frac{1}{2}$  or  $\frac{1}{3}$  part, or any other ratio of these quantities, and so on *ad infinitum*.

These kinds of questions are called by algebraists *indeterminate* or *unlimited* problems; and by an analytical process, theorems may be raised that will give all the *possible* answers.

## EXAMPLES.

1. A merchant would mix wines at 17*s*, 18*s*, and 22*s* per gallon, so as that the mixture may be worth 20*s* the gallon: what quantity of each must be taken?

$$\text{Here } 20 \left\{ \begin{array}{l} 17 \\ 18 \\ 22 \end{array} \right. \begin{array}{l} 2 \text{ at } 17s \\ 2 \text{ at } 18s \\ 3 + 2 = 5 \text{ at } 22s. \end{array}$$

Ans. 2 gallons at 17*s*, 2 gallons at 18*s*, and 5 at 22*s*.

2. How much wine at 6*s* per gallon, and at 4*s* per gallon, must be mixed together, that the composition may be worth 5*s* per gallon? Ans. 1 qt, or 1 gall, &c.

3. How much corn at 2*s* 6*d*, 3*s* 8*d*, 4*s*, and 4*s* 8*d* per bushel, must be mixed together; that the compound may be worth 3*s* 10*d* per bushel?

Ans. 12 at 2*s* 6*d*, 12 at 3*s* 8*d*, 18 at 4*s*, and 18 at 4*s* 8*d*.

4. A goldsmith has gold of 17, 18, 22, and 24 carats fine: how much must he take of each, to make it 21 carats fine?

Ans. 4 of 17, 4 of 18, 7 of 22, and 7 of 24.

5. It is required to mix brandy at 8*s*, wine at 7*s*, cyder at 1*s*, and water at 0 per gallon together, so that the mixture may be worth 5*s* per gallon?

Ans. 9 gals of brandy, 9 of wine, 5 of cyder, and 5 of water.

6. How much sugar at 4*d*, at 6*d*, and at 11*d* per lb, must be mixed together, so that the composition formed by them may be worth 7*d* per lb?

Ans. 1 lb, or 1 stone, or 1 cwt, or any other equal quantity of each sort.

## RULE II.

WHEN the whole composition is limited to a certain quantity:

Find an answer as before by linking; then say, as the sum of the quantities, or differences thus determined, is to the given quantity; so is each ingredient, found by linking, to the required quantity of each.

## EXAMPLES.

1. How much gold of 15, 17, 18 and 22 carats fine, must be mixed together, to form a composition of 40 oz of 20 carats fine?

Here

$$\text{Here } 20 \left\{ \begin{array}{r} 15 \\ 17 \\ 18 \\ \hline 22 \end{array} \right. - - - - \quad \underline{\quad 2 \quad} \\ 5 + 3 + 2 = 10$$

Then, 16

$$\text{as } 16 : 40 :: 2 : 5$$

$$\text{and } 16 : 40 :: 10 : 25$$

Anf. 5 oz of 15, 17, and 18 caracts fine, and 25 oz of 22 caracts fine \*.

Ex. 2. A grocer has currants at 4d, 6d, 9d, and 11d per lb. and he would make a mixture of 240lb, so that it might be afforded at 8d per lb; how much of each sort must he take?

Anf. 72lb at 4d, 24 at 6d, 48 at 9d, and 96 at 11d.

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\* A great number of questions might be here given relating to the specific gravities of metals, &c. but one of the most curious may here suffice.

Hiero, king of Syracuse, gave orders for a crown to be made entirely of pure gold; but suspecting the workman had debased it by mixing it with silver or copper, he recommended the discovery of the fraud to the famous Archimedes, and desired to know the exact quantity of alloy in the crown.

Archimedes, in order to detect the imposition, procured two other masses, the one of pure gold, the other of silver or copper, and each of the same weight with the former; and by putting each separately into a vessel full of water, the quantity of water expelled by them determined their specific gravities; from which, and their given weights, the exact quantities of gold and alloy in the crown may be determined.

Suppose the weight of each crown to be 10lb, and that the water expelled by the copper or silver was 92lb, by the gold 52lb, and by the compound crown 64lb; what will be the quantities of gold and alloy in the crown?

The rates of the simples are 92 and 52, and of the compound 64; therefore

$$64 \left| \begin{array}{r} 92 \\ 52 \end{array} \right. \begin{array}{l} 12 \text{ of copper} \\ 28 \text{ of gold} \end{array}$$

And the sum of these is  $12 + 28 = 40$ , which should have been but 10; therefore by the Rule,

$$\left. \begin{array}{l} 40 : 10 :: 12 : 3 \text{ lb of copper} \\ 40 : 10 :: 28 : 7 \text{ lb of gold.} \end{array} \right\} \text{the answer.}$$

## RULE III\*.

WHEN one of the ingredients is limited to a certain quantity; Take the difference between each price, and the mean rate as before; then say,

As the difference of that simple, whose quantity is given, is to the rest of the differences severally; so is the quantity given, to the several quantities required.

## EXAMPLES.

1. How much wine at 5s, at 5s 6d, and 6s the gallon, must be mixed with 3 gallons at 4s per gallon, so that the mixture may be worth 5s 4d per gallon?

$$\text{Here } 64 \left\{ \begin{array}{l} 48 \\ 60 \\ 66 \\ 72 \end{array} \right. \quad \begin{array}{l} 8+2=10 \\ 8+2=10 \\ 16+4=20 \\ 16+4=20 \end{array}$$

$$\text{Then } 10 : 10 :: 3 : 3$$

$$10 : 20 :: 3 : 6$$

$$10 : 20 :: 3 : 6$$

Anf. 3 gallons at 5s, 6 at 5s 6d, and 6 at 6s.

2. A grocer would mix teas at 12s, 10s, and 6s per lb, with 20lb at 4s per lb: how much of each sort must he take to make the composition worth 8s per lb?

Anf. 20lb at 4s, 10lb at 6s, 10lb at 10s, and 20lb at 12s.

3. How much gold of 15, of 17, and of 22 caracts fine, must be mixed with 5 oz of 18 caracts fine, so that the composition may be 20 caracts fine?

Anf. 5 oz of 15 caracts fine, 5 oz of 17, and 25 of 22.

\* In the very same manner questions may be wrought when several of the ingredients are limited to certain quantities, by finding first for one limit, and then for another.

The two last Rules can want no demonstration, as they evidently result from the first, the reason of which has been already explained.

## POSITION.

**POSITION** is a method of performing certain questions, which cannot be resolved by the common direct rules. It is sometimes called False Position, or False Supposition, because it makes a supposition of false numbers, to work with the same as if they were the true ones, and by their means discovers the true numbers sought. It is sometimes also called Trial-and-Error, because it proceeds by *trials* of false numbers, and thence finds out the true ones by a comparison of the *errors*.

Position is either Single or Double.

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## SINGLE POSITION.

**SINGLE POSITION** is that by which a question is resolved by means of one supposition only.

Questions which have their result proportional to their suppositions, belong to Single Position : such as those which require the multiplication or division of the number sought by any proposed number ; or when it is to be increased or diminished by itself, or any parts of itself, a certain proposed number of times.

## RULE.

TAKEN or assume any number for that which is required, and perform the same operations with it, as are described or performed in the question.

Then say, As the result of the said operation, is to the position, or number assumed ; so is the result in the question, to a fourth term, which will be the number sought \*.

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\* The reason of this Rule is evident, because it is supposed that the results are proportional to the suppositions.

Thus,  $nx : x :: na : a$ ,

$$\text{or } \frac{x}{n} : x :: \frac{a}{n} : a,$$

$$\text{or } \frac{x}{n} \pm \frac{x}{m}, \&c : x :: \frac{a}{n} \pm \frac{a}{m}, \&c : a,$$

and so on.

## EXAMPLES.

1. A person after spending  $\frac{1}{3}$  and  $\frac{1}{4}$  of his money, has yet remaining 60*l*; what had he at first?

Suppose he had at first 120*l*.

Now  $\frac{1}{3}$  of 120 is 40

$\frac{1}{4}$  of it is 30

their sum is 70  
which taken from 120

leaves 50

Proof.

$\frac{1}{3}$  of 144 is 48

$\frac{1}{4}$  of 144 is 36

their sum 84  
taken from 144

leaves 60 as  
per question.

Then, 50 : 120 :: 60 : 144, the Answer.

2. What number is that, which being multiplied by 7, and the product divided by 6, the quotient may be 14? Ans. 12.

3. What number is that, which being increased by  $\frac{1}{2}$ ,  $\frac{1}{3}$ , and  $\frac{1}{4}$ , of itself, the sum shall be 125? Ans. 60.

4. A general, after sending out a foraging  $\frac{1}{2}$  and  $\frac{1}{3}$  of his men, had yet remaining 700: what number had he in command? Ans. 4200.

5. A gentleman distributed 78 pence among a number of poor people, consisting of men, women, and children; to each man he gave 6*d*, to each woman 4*d*, and to each child 2*d*: moreover there were twice as many women as men, and thrice as many children as women. How many were there of each? Ans. 3 men, 6 women, and 18 children.

6. One being asked his age, said, if  $\frac{3}{5}$  of the years I have lived, be multiplied by 7, and  $\frac{2}{3}$  of them be added to the product, the sum will be 292. What was his age?

Ans. 60 years.

## DOUBLE POSITION.

DOUBLE POSITION is the method of resolving certain questions by means of two suppositions of false numbers.

To the Double Rule of Position belong such questions as have their results not proportional to their positions: such are those, in which the numbers sought, or their parts or their multiples, are increased or diminished by some given absolute number, which is no known part of the number sought.

## RULE \*.

TAKE or assume any two convenient numbers, and proceed with each of them separately, according to the conditions of the question, as in Single Position ; and find how much each result is different from the result mentioned in the question, calling these differences the *errors*, noting also whether the results are too great or too little.

Then multiply each of the said errors by the contrary supposition, namely, the first position by the second error, and the second position by the first error. Then,

If the errors are alike, divide the difference of the products by the difference of the errors, and the quotient will be the answer.

But if the errors are unlike, divide the sum of the products by the sum of the errors, for the answer.

*Note.* The errors are said to be alike, when they are either both too great or both too little ; and unlike, when one is too great and the other too little.

\* *Demonstr.* The Rule is founded on this supposition, namely, that the first error is to the second, as the difference between the true and first supposed number, is to the difference between the true and second supposed number ; when that is not the case, the exact answer to the question cannot be found by this Rule.—That the Rule is true, according to that supposition, may be thus proved.

Let  $a$  and  $b$  be the two suppositions, and  $A$  and  $B$  their results, produced by similar operations ; also  $r$  and  $s$  their errors, or the differences between the results  $A$  and  $B$  from the true result  $n$  ; and let  $x$  denote the number sought, answering to the true result  $n$  of the question.

Then is  $n - A = r$ , and  $n - B = s$ . And, according to the supposition on which the Rule is founded,  $r : s :: x - a : x - b$  ; hence, by multiplying extremes and means,  $rx - rb = sx - sa$  ; then, by transposition,  $rx - sa = rb - sb$  ; and, by division,  $x = \frac{rb - sa}{r - s}$  = the number sought, which is the Rule when the results are both too little.

If the results be both too great, so that  $A$  and  $B$  are both greater than  $n$  ; then  $n - A = -r$ , and  $n - B = -s$ , or  $r$  and  $s$  are both negative ; hence  $-r : -s :: x - a : x - b$ , but  $-r : -s :: +r : +s$ , therefore  $r : s :: x - a : x - b$ , and the rest will be exactly as in the former case.

But if one result  $A$  only be too little, and the other  $B$  too great, or one error  $r$  positive, and the other  $s$  negative, then the theorem becomes  $x = \frac{rb + sa}{r + s}$  which is the Rule in this case, or when the errors are unlike.

## EXAMPLES.

1. What number is that, which being multiplied by 6, the product increased by 18, and the sum divided by 9, the quotient shall be 20?

Suppose the two numbers 18 and 30. Then,

	First Position.	Second Position.	Proof.
18	Suppose	30	27
6	mult.	6	6
108		180	162
18	add	18	18
9) 126	div.	9) 198	9) 180
14	results	22	20
20	true ref.	20	<hr/>
+ 6	errors unlike	- 2	
2d pos. 30	mult.	18 1st pos.	
Er- { 2 180		36	
rors { 6 36		<hr/>	
sum 8 ) 216	sum of products		
27	Answer sought.		

## RULE II.

FIND, by trial, two numbers, as near the true number as convenient, and operate with them as in the question, marking the errors which arise from each of them.

Multiply the difference of the two numbers assumed, or found by trial, by the least error, and divide the product by the difference of the errors, when they are alike, but by their sum when they are unlike.

Add the quotient, last found, to the number belonging to the least error, when that number is too little, but subtract it when too great, and the result will give the true quantity sought \*.

## EXAMPLES.

1. So, the foregoing example worked by this 2d rule, will be as follows:

$$\begin{array}{rcl}
 30 \text{ positions } 18; & \text{their dif. } 12 \\
 - 2 \text{ errors } + 6; & \text{least error } 2 \\
 \text{sum of errors } 8 ) 24 \text{ (3 subtr.)} \\
 \text{from the position } 30 \\
 \text{leaves the answer } 27
 \end{array}$$

\* For since, by the supposition,  $r : s :: x-a : x-b$ , therefore by division,  $r-s : s :: b-a : x-b$ , which is the 2d Rule,

**Ex. 2.** A son asking his father how old he was, received this answer: Your age is now one-fourth of mine; but 5 years ago, your age was only one-fifth of mine. What then are their two ages?

Anf. 20 and 80.

**3.** A workman was hired for 30 days, at 2*s* 6*d* per day, for every day he worked; but with this condition, that for every day he played, he should forfeit 1*s*. Now it so happened, that upon the whole he had 2*l* 14*s* to receive. How many of the days did he work?

Anf. 24.

**4.** A and B began to play together with equal sums of money: A first won 20 guineas, but afterwards lost back  $\frac{2}{3}$  of what he then had; after which, B had 4 times as much as A. What sum did each begin with?

Anf. 100 guineas.

**5.** Two persons, A and B, have both the same income. A saves  $\frac{1}{5}$  of his; but B, by spending 50*l* per annum more than A, at the end of 4 years finds himself 100*l* in debt. What doth each receive and spend per annum?

Anf. They receive 125*l* per annum; also A spends 100*l*, and B spends 150*l* per annum.

## PERMUTATIONS AND COMBINATIONS.

**PERMUTATION** is the altering, changing, or varying the position or order of things; or the shewing how many different ways they may be placed.—This is otherwise called Alternation, Changes, or Variation; and the only thing to be regarded here, is the order they stand in; for no two parcels are to have all their quantities placed in the same situation: as, how many changes may be rung on a number of bells, or how many different ways any number of persons may be placed, or how many several variations may be made of any number of letters, or any other things proposed to be varied.

**COMBINATION** is the shewing how often a less number of things can be taken out of a greater, and combined together, without considering their places, or the order they stand in. This is sometimes called Election or Choice; and here every parcel must be different from all the rest, and no two are to have precisely the same quantities or things.

*Combinations of the same Form*, are those in which there are the same number of quantities, and the same repetitions: thus, *aabc*, *bbcd*, *ccde*, are of the same form; *aabc*, *abbb*, *aabb*, are of different forms.

*Composition*

*Composition of Quantities*, is the taking a given number of quantities, out of as many equal rows of different quantities, one out of every row, and combining them together.

Some illustrations of these definitions are in the following Problems :

### PROBLEM I.

*To assign the Number of Permutations, or Changes, that can be made of any Given Number of Things, all different from each other.*

#### RULE\*.

MULTIPLY all the terms of the natural series of numbers, from 1 up to the given number, continually together, and the last product will be the answer required.

#### EXAMPLES.

1. How many changes may be rung on 6 bells?

$$\begin{array}{r}
 1 \\
 2 \\
 \hline
 2 \\
 3 \\
 \hline
 6 \\
 4 \\
 \hline
 24 \\
 5 \\
 \hline
 120 \\
 6 \\
 \hline
 720 \text{ the Answer.}
 \end{array}$$

Or  $1 \times 2 \times 3 \times 4 \times 5 \times 6 = 720$  the Answer.

2. How many days can 7 persons be placed in a different position at dinner? Anſ. 5040 days.

\* The reason of the Rule may be shewn thus: any one thing  $a$  is capable only of one position, as  $a$ .

Any two things  $a$  and  $b$ , are only capable of two variations; as  $ab, ba$ ; whose number is expressed by  $1 \times 2$ .

If there be three things,  $a, b$ , and  $c$ ; then any two of them, leaving out the 3d, will have  $1 \times 2$  variations; and consequently, when the 3d is taken in, there will be  $1 \times 2 \times 3$  variations.

In the same manner, when there are 4 things, every three, leaving out the 4th, will have  $1 \times 2 \times 3$  variations; consequently by taking in successively the 4 left out, there will be  $1 \times 2 \times 3 \times 4$  variations. And so on as far as we please.

Ex. 3. How many changes may be rung on 12 bells, and what time would it require, supposing 10 changes to be rung in 1 minute, and the year to consist of 365 days, 5 hours, and 49 minutes?

Anf. 479001600 changes, and 91 years, 26 days, 22 hours, 41 minutes.

4. How many changes may be made of the words in the following verse : *Tot tibi sunt dotes, virgo, quot sidera caelo?*

Anf. 40320 changes.

### PROBLEM II.

*Any Number of different Things being given; to find how many Changes can be made out of them, by taking a Given Number of Quantities at a Time.*

#### RULE \*.

TAKE a series of numbers, beginning at the number of things given, and decreasing by 1 to the number of quantities

\* This Rule, expressed in algebraic terms, is as follows :

$m \times m - 1 \times m - 2 \times m - 3 \text{ &c. to } n \text{ terms}$ : where  $m =$  the number of things given, and  $n =$  the quantities to be taken at a time.

In order to demonstrate the Rule, it will be proper to premise the following Lemma :

LEMMA. The number of changes of  $m$  things, taken  $n$  at a time, is equal to  $m$  changes of  $m - 1$  things, taken  $n - 1$  at a time.

Demonstr. Let any five quantities,  $a b c d e$  be given.

First, leave out the  $a$ , and let  $v =$  the number of all the variations of every two,  $bc$ ,  $bd$ , &c. that can be taken out of the four remaining quantities  $b c d e$ .

Now, let  $a$  be put in the first place of each of them,  $a, b, c, a, b, d, \text{ &c.}$  and the number of changes will still remain the same; that is,  $v =$  the number of variations of every 3 out of the 5,  $a b c d e$ , when  $a$  is first.

In like manner, if  $b, c, d, e$  be successively left out, the number of variations of all the two's will also be  $= v$ ; and putting  $b, c, d, e$  respectively in the first place, to make 3 quantities out of 5, there will still be  $v$  variations, as before.

But these are all the variations that can happen of 3 things out of 5, when  $a, b, c, d, e$  are successively put first; and therefore the sum of all these is the sum of all the changes of 3 things out of 5.

But the sum of these is so many times  $v$ , as is the number of things; that is  $5v$ , or  $mv$ , = all the changes of 3 times out of 5.

And the same way of reasoning may be applied to any numbers whatever.

Demon. of the Rule. Let any 7 things,  $a b c d e f g$ , be given and let 3 be the number of quantities to be taken.

Then  $m = 7$ , and  $n = 3$ .

Now,

ties to be taken at a time, and the product of all the terms will be the answer required.

## EXAMPLES.

I. How many changes may be rung with 3 bells out of 8?

$$\begin{array}{r} 8 \\ \times 7 \\ \hline 56 \\ - 6 \\ \hline 336 \end{array}$$

the Answer.

Or,  $8 \times 7 \times 6$  (= 3 terms) = 336 the Answer.

2. How many words can be made with 5 letters of the alphabet, admitting that a number of consonants alone will not make a word?

Ansl. 5100480.

## PROBLEM III.

*Any Number of Things being given; of which there are several given Things of one Sort, and several of another, &c.; To find how many Changes can be made out of them all.*

## RULE \*.

TAKE the series  $1 \times 2 \times 3 \times 4$ , &c. up to the number of things given, and find the product of all the terms.

Take

Now, it is evident, that the number of changes that can be made by taking 1 by 1 out of 5 things, will be 5, which let =  $v$ .

Then, by the Lemma, when  $m = 6$ , and  $n = 2$ , the number of changes will be  $= mv = 6 \times 5$ ; which let be  $= v$  a second time.

Again, by the Lemma, when  $m = 7$  and  $n = 3$ , the number of changes is  $= mv = 7 \times 6 \times 5$ ; that is  $= mv = m \times (m-1) \times (m-2)$ , continued to 3, or  $n$  terms.

And the same may be shewn for any other numbers.

\* This Rule is expressed in terms thus:

$$1 \times 2 \times 3 \times 4 \times 5, \text{ &c to } m$$

$$1 \times 2 \times 3, \text{ &c to } p \times 1 \times 2 \times 3, \text{ &c to } q, \text{ &c.} :$$

where  $m$  = the number of things given,  $p$  = the number of things of the first sort,  $q$  = the number of things of the second sort, &c.

The Demonstration may be shewn as follows:

Any 2 quantities  $a b$ , both different, admit of 2 changes; but if the quantities are the same, or  $a b$  becomes  $a a$ , there will be only one position; which may be expressed by  $\frac{1 \times 2}{1 \times 2} = 1$ .

Any 3 quantities,  $a b c$ , all different from each other, afford 6 variations; but if the quantities be all alike, or  $a b c$  becomes  $a a a$ , then

Take the series  $1 \times 2 \times 3 \times 4$ , &c. up to the number of given things of the first sort, and the series  $1 \times 2 \times 3 \times 4$ , &c. up to the number of given things of the second sort, &c.

Divide the product of all the terms of the first series by the joint product of all the terms of the remaining ones, and the quotient will be the answer required.

## EXAMPLES.

1. How many variations can be made of the letters in the word Bacchanalia?

$$\begin{aligned}1 \times 2 & \text{ (= number of } c\text{'s)} = 2 \\1 \times 2 \times 3 \times 4 & \text{ (= number of } a\text{'s)} = 24 \\1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7 \times 8 \times 9 \times 10 \times 11 & \\& \text{ (= number of letters in the word)} = 39916800 \\2 \times 24 & = 48 \quad 39916800 \quad (831600 \text{ the Answer.}}\end{aligned}$$

151

76

288

then the 6 variations will be reduced to 1 ; which may be expressed by  $\frac{1 \times 2 \times 3}{1 \times 2 \times 3} = 1$ . Again, if two of the quantities only are alike, or  $a b c$  becomes  $a a c$ ; then the 6 variations will be reduced to these 3,  $a a c, c a a$ , and  $a c a$ ; which may be expressed by  $\frac{1 \times 2 \times 3}{1 \times 2} = 3$ .

Any 4 quantities,  $a b c d$ , all different from each other, will admit of 24 variations. But if the quantities be the same, or  $a b c d$  becomes  $a a a a$ , the number of variations will be reduced to one; which is  $\frac{1 \times 2 \times 3 \times 4}{1 \times 2 \times 3 \times 4} = 1$ .

Again, if three of the quantities only be the same, or  $a b c d$  becomes  $a a a b$ , the number of variations will be reduced to these 4,  $a a a b, a a b a, a b a a$ , and  $b a a a$ ; which is  $\frac{1 \times 2 \times 3 \times 4}{1 \times 2 \times 3} = 4$ .

And thus it may be shewn, that if two of the quantities be alike, or the 4 quantities be  $a a b c$ , the number of variations will be reduced to 12; which may be expressed by  $\frac{1 \times 2 \times 3 \times 4}{1 \times 2} = 12$ .

And by reasoning in the same manner, it will appear, that the number of changes which can be made of the quantities  $a b b c c$ , is equal to 60; which may be expressed by  $\frac{1 \times 2 \times 3 \times 4 \times 5 \times 6}{1 \times 2 \times 1 \times 2 \times 3} = 60$ . And so on for any other quantities whatever.

Ex. 2.

Ex. 2. How many different numbers can be made of the following figures, 1220005555? Anf. 12600.

3. How many varieties will take place in the succession of the following musical notes, fa, fa, fa, sol, sol, la, mi, fa? Anf. 3360.

#### PROBLEM IV.

*To find the Changes of any Given Number of Things, taking a Given Number at a Time; in which there are several Given Things of one Sort, several of another, &c.*

#### RULE\*.

FIND all the different forms of combination of all the given things, taken as many at a time as in the question.

Find the number of changes in any form, and multiply it by the number of combinations in that form.

Do the same for every distinct form, and the sum of all the products will give the whole number of changes required.

#### EXAMPLES.

1. How many alternations, or changes, can be made of every four letters out of these 8, aaabbbcc?

No. of forms.	No. of changes.
$a^3b$ , $a^3c$ , $b^3a$ , $b^3c$ . . . . .	4
$a^2b^2$ , $a^2c^2$ , $b^2c^2$ . . . . .	6
$a^2bc$ , $b^2ac$ , $c^2ab$ . . . . .	12

\* The reason of this rule is plain from what has been shewn before, and the nature of the problem.

#### *A Rule for finding the Number of Forms.*

1. PLACE the things so, that the greatest indices may be first, and the rest in order.

2. Begin with the first letter, and join it to the second, third, fourth, &c. to the last.

3. Then take the second letter, and join it to the third, fourth, &c. to the last. And so on, till they are entirely exhausted, always remembering to reject such combinations as have occurred before, and this will give the combinations of all the two's.

4. Join the first letter to every one of the two's, and the second, third, &c. as before; and it will give the combinations of all the three's.

5. Proceed in the same manner to get the combinations of all the four's, &c. and you will at last get all the several forms of combinations, and the number in each form.

Therefore

$$\text{Therefore } \left\{ \begin{array}{l} 4 \times 4 = 16 \\ 3 \times 6 = 18 \\ 3 \times 12 = 36 \end{array} \right. \quad \frac{70}{\text{—}} = \text{number of changes required.}$$

Ex. 2. How many changes can be made of every 8 letters out of these 10; *aaaabbccde*? Ans. 22260.

3. How many different numbers can be made out of 1 unit, 2 twos, 3 threes, 4 fours, and 5 fives; taken 5 at a time?

Ans. 2111.

### PROBLEM V.

*To find the Number of Combinations of any Given Number of Things, all different from each other, taken any Given Number at a Time.*

#### RULE\*.

TAKE the series 1, 2, 3, 4, &c, up to the number to be taken at a time, and find the product of all the terms.

Take

\* This Rule, expressed algebraically, is,

$\frac{m}{1} \times \frac{m-1}{2} \times \frac{m-2}{3} \times \frac{m-3}{4} \times \dots$  &c, to  $n$  terms; where  $m$  is the number of given quantities, and  $n$  those to be taken at a time.

*Demonstr.* of the Rule. 1. Let the number of things to be taken at a time be 2, and the things to be combined =  $m$ .

Now, when  $m$ , or the number of things to be combined, is only two, as  $a$  and  $b$ , it is evident that there can be but one combination, as  $ab$ ; but if  $m$  be increased by one, or the letters to be combined be 3, as  $a, b, c$ ; then it is plain that the number of combinations will be increased by 2, since with each of the former letters  $a$  and  $b$ , the new letter  $c$  may be joined. In this case therefore, it is evident that the whole number of combinations will be truly expressed by  $1+2$ .

Again, if  $m$  be increased by one letter more, or the whole number of letters be four, as  $a, b, c, d$ ; then it will appear that the whole number of combinations must be increased by 3, since with each of the preceding letters the new letter  $d$  may be combined. The combinations, therefore, in this case, will be truly expressed by  $1+2+3$ .

And in the same manner it may be shewn that the whole number of combinations of 2, in 5 things, will be  $1+2+3+4$ ; of 2, in 6 things,  $1+2+3+4+5$ ; and of 2, in 7 things,  $1+2+3+4+5+6$ , &c.: whence, universally, the number of combinations

Take a series of as many terms, decreasing by 1, from the given number, out of which the election is to be made, and find the product of all the terms.

Divide the last product by the former, and the quotient will be the number sought.

### EXAMPLES.

1. How many combinations can be made of 6 letters out of ten?

$$1 \times 2 \times 3 \times 4 \times 5 \times 6 \text{ (= the number to be taken at a time)} = 720.$$

$$10 \times 9 \times 8 \times 7 \times 6 \times 5 \text{ (= same number from 10)} = 151200.$$


---

of  $m$  things, taken 2 by 2, is  $= 1 + 2 + 3 + 4 + 5 + 6$ , &c. to  $(m - 1)$  terms.

But the sum of this series is  $= \frac{m}{1} \times \frac{m - 1}{2}$ ; which is the same as the rule.

2. Let now the number of quantities in each combination be supposed to be three.

Then it is plain, that when  $m = 3$ , or the things to be combined are  $a, b, c$ , there can be only one combination. But if  $m$  be increased by 1, or the things to be combined are 4, as  $a, b, c, d$ , then will the number of combinations be increased by 3: since 3 is the number of combinations of 2 in all the preceding letters,  $a, b, c$ , and with each two of these the new letter  $d$  may be combined.

The number of combinations, therefore, in this case, is  $1 + 3$ .

Again, if  $m$  be increased by one more, or the number of letters be supposed 5; then the former number of combinations will be increased by 6, that is, by all the combinations of 2 in the 4 preceding letters,  $a, b, c, d$ ; since, as before, with each two of those the new letter  $c$  may be combined.

The number of combinations, therefore, in this case, is  $1 + 3 + 6$ .

Whence, universally, the number of combinations of  $m$  things, taken 3 by 3, is  $1 + 3 + 6 + 10$ , &c. to  $m - 2$  terms:

But the sum of this series is  $= \frac{m}{1} \times \frac{m - 1}{2} \times \frac{m - 2}{3}$ ; which is the same as the rule.

And the same thing will hold, let the number of things to be taken at a time be what it will; therefore the number of combinations of  $m$  things, taken  $n$  at a time, will be =

$$\frac{m}{1} \times \frac{m - 1}{2} \times \frac{m - 2}{3} \times \frac{m - 3}{4}, \text{ &c. to } n \text{ terms. Q. E. D.}$$

Then 720 ) 151200 ( 210 the Answer.

$$\begin{array}{r} 1440 \\ \hline 720 \\ \hline 720 \end{array}$$

2. How many combinations can be made of 2 letters out of the 24 letters of the alphabet? Ans. 276.

3. A general, who had often been successful in war, was asked by his king what reward he should confer upon him for his services; the general only desired a farthing for every file, of 10 men in a file, which he could make with a body of 100 men; what is the amount in pounds sterling?

Ans. 18031572350l 9s 2d.

#### PROBLEM VI.

*To find the Number of Combinations of any Given Number of Things, by taking any Given Number at a Time; in which there are several Things of one Sort, several of another, &c.*

#### RULE.

FIND, by trial, the number of different forms which the things to be taken at a time will admit of, and the number of combinations there are in each.

Add all the combinations, thus found, together, and the sum will be the number required.

#### EXAMPLES.

1. Let the things proposed be  $a a a b b c$ ; it is required to find the number of combinations made of every 3 of these quantities?

Forms.	Combinations.
$a^3$	1
$a^2b$ , $a^2c$ , $b^2a$ , $b^2c$	4
$a b c$	1

Number of combinations required = 6

2. Let  $a a a b b b c c$  be proposed; it is required to find the number of combinations of these quantities, taken 4 at a time? Ans. 10.

3. How many combinations are there in  $a a a a b b c c d e$ , taking 8 at a time? Ans. 13.

4. How many combinations are there in  $a a a a a b b b b b$   
 $c e c c d d d d e e e f f f g$ , taking 10 at a time? Ans. 2819.

## PROBLEM VII.

To find the Compositions of any Number, in an equal Number of Sets, the Things themselves being all different.

## RULE\*.

MULTIPLY the number of things in every set continually together, and the product will be the answer required.

## EXAMPLES.

1. Suppose there are four companies, in each of which there are 9 men; it is required to find how many ways 9 men may be chosen, one out of each company?

$$\begin{array}{r} 9 \\ 9 \\ \hline 81 \\ 9 \\ \hline 729 \\ 9 \\ \hline 6561 \end{array}$$

the Answer.

Or,  $9 \times 9 \times 9 \times 9 = 6561$  the Answer.

\* *Demonstr.* Suppose there are only two sets; then, it is plain, that every quantity of the one set being combined with every quantity of the other, will make all the compositions, of two things in these two sets; and the number of these compositions is evidently the product of the number of quantities in one set by that in the other.

Again, suppose there are three sets; then the composition of two in any two of the sets, being combined with every quantity of the third, will make all the compositions of three in the three sets. That is, the compositions of two, in any two of the sets, being multiplied by the number of quantities in the remaining set, will produce the compositions of three in the three sets; which is evidently the continual product of all the three numbers in the three sets.

And the same manner of reasoning will hold, let the number of sets be what it will. Q. E. D.

The doctrine of permutations, combinations, &c. is of very extensive use in different parts of the Mathematics; particularly in the calculation of annuities and chances. The subject might have been pursued to a much greater length; but what is here done will be found sufficient for most of the purposes to which things of this nature are applicable.

Ex. 2. Suppose there are 4 companies; in one of which there are 6 men, in another 8, and in each of the other two 9; what are the choices, by a composition of 4 men, one out of each company?

Anf. 3888.

3. How many changes are there in throwing 5 dice?

Anf. 7776.

### PRACTICAL QUESTIONS IN ARITHMETIC.

QUEST. 1. The swiftest velocity of a cannon-ball, is about 2000 feet in a second of time. Then in what time, at that rate, would such a ball be in moving from the earth to the sun, admitting the distance to be 100 millions of miles, and the year to contain 365 days 6 hours?

Anf.  $8\frac{4808}{13149}$  years,

QUEST. 2. What is the ratio of the velocity of light to that of a cannon-ball, which issues from the gun with a velocity of 1500 feet per second; light passing from the sun to the earth in  $7\frac{1}{2}$  minutes? Anf. the ratio of  $7822\frac{2}{9}$  to 1.

QUEST. 3. The slow or parade-step being 70 paces per minute, at 28 inches each pace, it is required to determine at what rate per hour that movement is? Anf.  $1\frac{113}{52}$  miles.

QUEST. 4. The quick-time or step, in marching, being 2 paces per second, or 120 per minute, at 28 inches each; then at what rate per hour does a troop march on a route, and how long will they be in arriving at a garrison 20 miles distant, allowing a halt of one hour by the way to refresh?

Anf. { the rate is  $3\frac{2}{11}$  miles an hour,  
and the time  $7\frac{2}{7}$  hr, or  $7 h 17\frac{1}{7}$  min.

QUEST. 5. Two persons, A and B, being on opposite sides of a wood, which is 268 yards about, they begin to go round it, both the same way, at the same instant of time; A goes at the rate of 11 yards per minute, and B 34 yards in 3 minutes; the question is, how many times will the wood be gone round before the quicker overtake the slower?

Anf. 17 times.

QUEST. 6. To determine how far 50 millions of guineas will reach, when laid down in a straight line touching one another; supposing each guinea to be an inch in diameter, as it is very nearly. Anf. 7891 miles, 728 yds, 2 ft, 8 in.

QUEST. 7. A wall was to be built 700 yards long in 29 days. Now, after 12 men had been employed on it for 11 days, it was found that they had completed only 220 yards of the

the wall. It is required then to determine how many men must be added to the former, that the whole number of them may just finish the wall in the time proposed, at the same rate of working.

Anf. 4 men to be added.

QUEST. 8. The hour and minute hand of a clock are exactly together at 12 o'clock; when are they next together?

Anf. at  $1\frac{1}{11}$  hr, or 1 hr  $5\frac{5}{11}$  min.

QUEST. 9. A person after spending  $10l$  more than  $\frac{1}{3}$  of his yearly income, had then remaining  $15l$  more than the half of it; what was his income?

Anf.  $150l$ .

QUEST. 10. A person who was possessed of a  $\frac{3}{5}$  share of a copper mine, sold  $\frac{3}{4}$  of his interest in it for  $1710l$ ; what was the reputed value of the whole at the same rate?

Anf.  $3800l$ .

QUEST. 11. A can do a piece of work alone in 10 days, and B alone in 13; in what time will they both together perform a like quantity of work?

Anf.  $5\frac{5}{23}$  days.

QUEST. 12. A person bought 120 oranges at 2 a penny, and 120 more at 3 a penny; after which, telling them out again at 5 for 2 pence, whether did he gain or lose by the bargain?

Anf. he lost 4 pence.

QUEST. 13. If a gentleman whose annual income is  $1200l$ , spend 20 guineas a week; whether will he save or run in debt, and how much in the year?

Anf. save  $108l$ .

QUEST. 14. In the latitude of London, the distance round the earth, measured on the parallel of latitude, is about 15550 miles; now as the earth turns round in 23 hours 56 minutes, at what rate per hour is the city of London carried by this motion from west to east?

Anf.  $649\frac{2}{3}\frac{5}{9}$  miles an hour.

QUEST. 15. If a quantity of provisions serves 1500 men 12 weeks, at the rate of 20 ounces a day for each man; how many men will the same provisions maintain for 20 weeks, at the rate of 8 ounces a day for each man?

Anf. 2250 men.

QUEST. 16. If 1000 men, besieged in a town, with provisions for 5 weeks, allowing each man 16 ounces a day, be reinforced with 500 men more; and supposing that they cannot be relieved till the end of 8 weeks, how many ounces a day must each man have, that the provision may last that time?

Anf.  $6\frac{2}{3}$  ounces.

QUEST. 17. A father left his son a fortune,  $\frac{1}{4}$  of which he ran through in 8 months:  $\frac{3}{7}$  of the remainder lasted him 12 months longer; after which he had bare  $410l$  left. What sum did the father bequeath the son?

Anf.  $956l\ 13s\ 4d$ .

QUEST. 18. A person, looking on his watch, was asked what was the time of the day, who answered, It is between 4 and 5; but a more particular answer being required, he said

said that the hour and minute hands were then exactly together : What was the time ?      Ans.  $21\frac{9}{11}$  min. past 4.

QUEST. 19. If 20 men can perform a piece of work in 12 days, how many men will accomplish another thrice as large in one-fifth of the time ?      Ans. 300.

QUEST. 20. A younger brother received 6300*l*, which was just  $\frac{7}{9}$  of his elder brother's fortune : What was the father worth at his death ?      Ans. 14400*l*.

QUEST. 21. A person, making his will, gave to one child  $\frac{13}{26}$  of his estate, and the rest to another. When these legacies came to be paid, the one turned out 600*l* more than the other : What did the testator die worth ?      Ans. 2000*l*.

QUEST. 22. A father devised  $\frac{7}{15}$  of his estate to one of his sons, and  $\frac{7}{15}$  of the residue to another, and the surplus to his relict for life. The children's legacies were found to be 257*l* 3*s* 4*d* different : Pray what money did he leave the widow the use of ?      Ans. 635*l* 0*s* 10 $\frac{3}{4}$ <sup>0</sup>*d*.

QUEST. 23. Two persons, A and B, travel between London and Exeter. A leaves Exeter at 8 o'clock in the morning, and walks at the rate of 3 miles an hour, without intermission ; and B sets out from London at 4 o'clock the same evening, and walks for Exeter at the rate of 4 miles an hour constantly. Now, supposing the distance between the two cities to be 130 miles, whereabouts on the road will they meet ?      Ans. 69 $\frac{3}{7}$  miles from Exeter.

QUEST. 24. Two persons, A and B, travel between London and Lincoln, distant 100 miles, A from London, and B from Lincoln, at the same instant. After 7 hours they meet on the road, when it appeared that A had rode  $1\frac{1}{2}$  miles an hour more than B. At what rate per hour then did each of the travellers ride ?      Ans. A  $7\frac{2}{5}$ , and B  $6\frac{1}{2}$  miles.

QUEST. 25. The clocks of Italy go on to 24 hours : Then how many strokes do they strike in one complete revolution of the index ?      Ans. 300.

QUEST. 26. One hundred eggs being placed on the ground, in a straight line, at the distance of a yard from each other : How far will a person travel who shall bring them one by one to a basket, which is placed at one yard from the first egg ?      Ans. 10100 yds, or 5 miles and 1300 yds.

QUEST. 27. One Sessa, an Indian, having invented the game of chess, shewed it to his prince, who was so delighted with it, that he promised him any reward he should ask ; on which Sessa requested that he might be allowed one grain of wheat for the first square on the chess board, 2 for the second, 4 for the third, and so on, doubling continually, to 64, the whole number of squares. Now, supposing a pint to contain

7680 of these grains, and one quarter or 8 bushels to be worth 27*s 6d*, it is required to compute the value of all the corn?

Anf, 6450468216285*l 17s 5d 3<sup>32</sup><sub>32</sub>7<sup>5</sup><sub>7</sub>q.*

QUEST. 28. Two young gentlemen, without private fortune, obtain commissions at the same time, and at the age of 18. One thoughtlessly spends 10*l* a year more than his pay; but, shocked at the idea of not paying his debts, gives his creditor a bond for the money, at the end of every year, and also insures his life for the amount; each bond costs him 30 shillings, besides the lawful interest of 5 per cent. and to insure his life costs him 6 per cent.

The other, having a proper pride, is determined never to run in debt; and, that he may assist a friend in need, perseveres in saving 10*l* every year, for which he obtains an interest of 5 per cent. which interest is every year added to his savings, and laid out, so as to answer the effect of compound interest.

Suppose these two officers to meet at the age of 50, when each receives from Government 400*l* per annum; that the one, seeing his past errors, is resolved in future to spend no more than he actually has, after paying the interest for what he owes, and the insurance on his life.

The other, having now something before hand, means in future to spend his full income, without increasing his stock.

It is desirable to know how much each has to spend per annum, and what money the latter has by him to assist the distressed, or leave to those who deserve it?

# LOGARITHMS AND ALGEBRA;

BEING

PART II. OF VOL. I.



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*OF PART II., VOLUME I.*

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LOGARITHMS.

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# LOGARITHMS,

AND

## ALGEBRA,

### OF LOGARITHMS\*.

LOGARITHMS are made to facilitate troublesome calculations in numbers. This they do, because they perform multiplication by only addition, and division by only subtraction, and raising of powers by multiplying the logarithm by the index of the power, and extracting of roots by dividing the logarithm of the number by the index of the root. For, logarithms are numbers so contrived, and adapted to other numbers, that the sums and differences of the former shall correspond

\* The invention of Logarithms is the undoubted right of Lord Napier, Baron of Merchiston, in Scotland, and is properly considered as one of the most useful and excellent discoveries of modern times. A table of these numbers was first published by him at Edinburgh, in the year 1614, in a treatise entitled *Canon Mirificum Logarithmorum*; and as their great utility and extensive application were sufficiently apparent, they were immediately received by all the learned throughout Europe. Mr. Henry Briggs, then professor of geometry at Gresham College, on hearing of the discovery, set out upon a visit to the noble inventor, and soon afterwards they jointly undertook the arduous task of computing new tables on this subject, and reducing them to a more convenient form than that which was at first thought of. But Lord Napier dying before they were finished, the whole burden fell upon Mr. Briggs, who, with prodigious labour and great skill, made an entire Canon, according to the new form, for all numbers from 1 to 20000, and from 90000 to 10100, to 14 places of figures, and published it at London in the year 1624, in a treatise entitled *Arithmetica Logarithmica*, with directions for supplying the intermediate chiliads.

correspond to, and shew, the products and quotients of the latter, &c.

Or, more generally, logarithms are the numerical exponents of ratios; or they are a series of numbers in arithmetical progression, answering to another series of numbers in geometrical progression.

Thus  $\begin{cases} 0, 1, 2, 3, 4, 5, 6, \text{ Indices, or logarithms.} \\ 1, 2, 4, 8, 16, 32, 64, \text{ Geometric progression.} \end{cases}$

Or  $\begin{cases} 0, 1, 2, 3, 4, 5, 6, \text{ Indices, or logarithms.} \\ 1, 3, 9, 27, 81, 243, 729, \text{ Geometric progression.} \end{cases}$

Or  $\begin{cases} 0, 1, 2, 3, 4, 5, \text{ Indices, or logs.} \\ 1, 10, 100, 1000, 10000, 100000, \text{ Geom. progres.} \end{cases}$

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This Canon was again published in Holland by Adrian Vlacq, anno 1628, together with the Logarithms of all the numbers which Mr. Briggs had omitted; but he contracted them down to 10 places of decimals. Mr. Briggs also computed the Logarithms of the sines, tangents, and secants, to every degree, and centesim, or 100th part of a degree, of the whole quadrant; and subjoined them to the natural sines, tangents, and secants, which he had before computed, to 15 places of figures. These Tables, together with their construction and use, were first published in the year 1633, after Mr. Briggs's death, by Mr. Henry Gellibrand, under the title of *Trigonometria Britannica*.

Benjamin Uisinus also gave a Table of Napier's Logs. and of sines, to every 10 seconds. And Chr. Wolf, in his Mathematical Lexicon, says that one Van Lofer had computed them to every single second, but his untimely death prevented their publication.

A great number of other authors have treated on this subject; but as their numbers are frequently inaccurate and incommodiously disposed, they are now generally neglected. The Tables in most repute at present, are those of Gardiner in 4to, first published in the year 1742; and my own Tables in 8vo, first printed in the year 1785, where the Logarithms of all numbers may be easily found from 1 to 10000000; and those of the sines, tangents, and secants, to any degree of accuracy required.

Also, Mr. Michael Taylor's Tables in large 4to, containing the common logarithms, and the logarithmic sines and tangents to every second of the quadrant. And, in France, the new book of logarithms by Callet; the 2d edition of which, in 1795, has the tables still farther extended, and are printed with what are called stereotypes, the types in each page being soldered together into a solid mass or block.

Dodson's Antilogarithmic Canon is likewise a very elaborate work, and of use for finding the numbers answering to any given logarithm.

Where.

Where it is evident, that the same indices serve equally for any geometric series; and consequently there may be an endless variety of systems of logarithms, to the same common numbers, by only changing the second term, 2, 3, or 10, &c. of the geometrical series of whole numbers; and by interpolation the whole system of numbers may be made to enter the geometric series, and receive their proportional logarithms, whether integers or decimals.

It is also apparent, from the nature of these series, that if any two indices be added together, their sum will be the index of that number which is equal to the product of the two terms, in the geometric progression, to which those indices belong.

Thus, the indices 2 and 3, being added together, make 5; and the numbers 4 and 8, or the terms corresponding to those indices, being multiplied together, make 32, which is the number answering to the index 5.

In like manner, if any one index be subtracted from another, the difference will be the index of that number which is equal to the quotient of the two terms to which those indices belong.

Thus, the index 6, minus the index 4, is = 2; and the terms corresponding to those indices are 64 and 16, whose quotient is = 4, which is the number answering to the index 2.

For the same reason, if the logarithm of any number be multiplied by the index of its power, the product will be equal to the logarithm of that power.

Thus, the index or logarithm of 4, in the above series, is 2; and if this number be multiplied by 3, the product will be = 6; which is the logarithm of 64, or the third power of 4.

And, if the logarithm of any number be divided by the index of its root, the quotient will be equal to the logarithm of that root.

Thus, the index or logarithm of 64 is 6; and if this number be divided by 2, the quotient will be = 3; which is the logarithm of 8, or the square root of 64.

The logarithms most convenient for practice, are such as are adapted to a geometric series increasing in a tenfold proportion, as in the last of the above forms; and are those which are to be found, at present, in most of the common tables on this subject.

The distinguishing mark of this system of logarithms is; that the index or logarithm of 10 is 1; that of 100 is 2; that of 1000 is 3; &c. And, in decimals, the logarithm of 1 is -1; that of .01 is -2; that of .001 is -3; &c. The log. of 1 being 0 in every system.

From whence it follows, that the logarithm of any number between 1 and 10, must be 0 and some fractional parts; and that of a number between 10 and 100, will be 1 and some fractional parts; and so on, for any other number whatever.

And since the integral part of a logarithm, usually called the Index, or Characteristic, is always thus readily found, it is commonly omitted in the tables; being left to be supplied by the operator himself, as occasion requires.

Another definition of Logarithms is, that the logarithm of any number is the index of that power of some other number, which is equal to the given number. So, if there be  $N = r^n$ , then  $n$  is the log. of  $N$ ; where  $n$  may be either positive or negative, or nothing, and the root  $r$  any number whatever, according to the different systems of logarithms.

When  $n$  is = 0, then  $N$  is = 1, whatever the value of  $r$  is; which shews, that the log. of 1 is always 0, in every system of logarithms.

When  $n$  is = 1, then  $N$  is =  $r$ ; so that the radix  $r$  is always that number whose log. is 1, in every system.

When the radix  $r$  is = 2.718281828459 &c, the indices  $n$  are the hyperbolic or Napier's log. of the numbers  $N$ ; so that  $n$  is always the hyp. log. of the number  $N$  or  $(2.718 \&c.)^n$ .

But when the radix  $r$  is = 10, then the index  $n$  becomes the common or Briggs's log. of the number  $N$ ; so that the common log. of any number  $10^n$  or  $N$ , is  $n$  the index of that power of 10 which is equal to the said number. Thus 100, being the second power of 10, will have 2 for its logarithm; and 1000, being the third power of 10, will have 3 for its logarithm: hence also, if 50 be =  $10^{1.69897}$ , then is 1.69897 the common log. of 50. And, in general, the following decuple series of terms,

viz.  $10^4$ ,  $10^3$ ,  $10^2$ ,  $10^1$ ,  $10^0$ ,  $10^{-1}$ ,  $10^{-2}$ ,  $10^{-3}$ ,  $10^{-4}$ , or 10000, 1000, 100, 10, 1, -1, -2, -3, -4, have 4, 3, 2, 1, 0, -1, -2, -3, -4, for their logarithms, respectively. And from this scale of numbers and logarithms, the same properties easily follow, as above mentioned.

## PROBLEM.

To compute the Logarithm to any of the Natural Numbers  
1, 2, 3, 4, 5, &c.

## RULE I\*.

1. TAKE the geometrical series, 1, 10, 100, 1000, 10000, &c., and apply to it the arithmetical series, 0, 1, 2, 3, 4, &c., as logarithms.

2. Find a geometric mean between 1 and 10, 10 and 100, or any other two adjacent terms of the series, betwixt which the number proposed lies.

3. Between the mean, thus found, and the nearest extreme, find another geometrical mean, in the same manner; and so on, till you are arrived within the proposed limit of the number whose logarithm is sought.

4. Find as many arithmetical means, in the same order as you found the geometrical ones, and the last of these will be the logarithm answering to the number required.

## EXAMPLE.

Let it be required to find the logarithm of 9.

Here the proposed number lies between 1 and 10.

First, then, the log. of 10 is 1, and the log. of 1 is 0;

theref.  $1 + 0 \div 2 = \frac{1}{2} = .5$  is the arithmetical mean,  
and  $\sqrt{10 \times 1} = \sqrt{10} = 3.1622777$  the geom. mean;  
hence the log. of 3.1622777 is .5.

Secondly, the log. of 10 is 1, and the log. of 3.1622777 is .5;

theref.  $1 + .5 \div 2 = .75$  is the arithmetical mean,  
and  $\sqrt{10 \times 3.1622777} = \sqrt{5.6234132} = 2.309422$  the geom. mean;  
hence the log. of 2.309422 is .75.

Thirdly, the log. of 10 is 1, and the log. of 2.309422 is .75;

theref.  $1 + .75 \div 2 = .875$  is the arithmetical mean,  
and  $\sqrt{10 \times 2.309422} = \sqrt{5.011872} = 2.2409422$  the geom. mean;  
hence the log. of 2.2409422 is .875.

Fourthly, the log. of 10 is 1, and the log. of 2.2409422 is .875;

theref.  $1 + .875 \div 2 = .9375$  is the arithmetical mean,  
and  $\sqrt{10 \times 2.2409422} = \sqrt{4.999999} = 2.23705$  the geom. mean;  
hence the log. of 2.23705 is .9375.

\* The reader who wishes to inform himself more particularly concerning the history, nature, and construction of Logarithms, may consult the Introduction to my Mathematical Table, lately published, where he will find his curiosity gratified.

Fifthly, the log. of 10 is 1, and the log. of 8·6596431 is .9375; theref.  $1 + .9375 \div 2 = .96875$  is the arithmetical mean, and  $\sqrt{10 \times 8.6596431} = 9.3057204$  the geom. mean; hence the log. of 9.3057204 is .96875.

Sixthly, the log. of 8.6596431 is .9375, and the log. of 9.3057204 is .96875; theref.  $.9375 + .96875 \div 2 = .953125$  is the arith. mean, and  $\sqrt{8.6596431 \times 9.3057204} = 8.9768713$  the geometric mean; hence the log. of 8.9768713 is .953125.

And proceeding in this manner, after 25 extractions, it will be found that the logarithm of 8.9999998 is .9542425; which may be taken for the logarithm of 9, as it differs so little from it, that it is sufficiently exact for all practical purposes.

And in this manner were the logarithms of almost all the prime numbers at first computed.

#### RULE II\*.

LET  $b$  be the number whose logarithm is required to be found; and  $a$  the number next less than  $b$ , so that  $b-a=1$ , the logarithm of  $a$  being known; and let  $s$  denote the sum of the two numbers  $a+b$ . Then

1. Divide the constant decimal .8685889638 &c, by  $s$ , and reserve the quotient: divide the reserved quotient by the square of  $s$ , and reserve this quotient: divide this last quotient also by the square of  $s$ , and again reserve the quotient: and thus proceed, continually dividing the last quotient by the square of  $s$ , as long as division can be made.

2. Then write these quotients orderly under one another, the first uppermost, and divide them respectively by the odd numbers 1, 3, 5, 7, 9, &c, as long as division can be made; that is, divide the first reserved quotient by 1, the second by 3, the third by 5, the fourth by 7, and so on.

3. Add all these last quotients together, and the sum will be the logarithm of  $b \div a$ ; therefore to this logarithm add also the given logarithm of the said next less number  $a$ , so will the last sum be the logarithm of the number  $b$  proposed.

\* For the demonstration of this rule, see the Mathematical Tables, p. 109, &c.

That is,

$$\text{Log. of } b \text{ is } \log. a + \frac{n}{s} \times \left( 1 + \frac{1}{3s^2} + \frac{1}{5s^4} + \frac{1}{7s^6} + \text{ &c.} \right)$$

where  $n$  denotes the constant given decimal .3685889638 &c.

### EXAMPLES.

**Ex. 1.** Let it be required to find the log. of the number 2. Here the given number  $b$  is 2, and the next less number  $a$  is 1, whose log. is 0; also the sum  $2+1=3=s$ , and its square  $s^2=9$ . Then the operation will be as follows:

3 )	.868588964	1 )	.289529654	( .289529654
9 )	.289529654	3 )	32169962	( 10723321
9 )	32169962	5 )	3574440	714888
9 )	3574440	7 )	397160	56737
9 )	397160	9 )	44129	4903
9 )	44129	11 )	4903	446
9 )	4903	13 )	545	42
9 )	545	15 )	61	4
9 )	61			
			log. of $\frac{2}{1}$ -	.301029995
			add log. 1 -	.000000000
			log. of 2 -	.301029995

**Ex. 2.** To compute the logarithm of the number 3.

Here  $b=3$ , the next less number  $a=2$ , and the sum  $a+b=5=s$ , whose square  $s^2$  is 25, to divide by which, always multiply by .04. Then the operation is as follows:

5 )	.868588964	1 )	.173717793	( .173717793
25 )	173717793	3 )	6948712	( 2316237
25 )	6948712	5 )	277948	55390
25 )	277948	7 )	11118	1588
25 )	11118	9 )	445	50
25 )	445	11 )	18	2
	18			
			log. of $\frac{3}{2}$ -	.176091260
			log. of 2 add	.301029995
			log. of 3 sought	.477121255

Then, because the sum of the logarithms of numbers, gives the logarithm of their product; and the difference of the logarithms, gives the logarithm of the quotient of the numbers;

numbers; from the above two logarithms, and the logarithm of 10, which is 1, we may raise a great many logarithms, as in the following examples:

## EXAMPLE 4.

$$\begin{array}{l} \text{Because } 2 \times 2 = 4, \text{ therefore} \\ \text{to log. } 2 - \cdot 301029995 \frac{2}{3} \\ \text{add log. } 2 - \cdot 301029995 \frac{2}{3} \\ \hline \text{sum is log. } 4 \cdot 602059991 \frac{1}{3} \end{array}$$

## EXAMPLE 5.

$$\begin{array}{l} \text{Because } 2 \times 3 = 6, \text{ therefore} \\ \text{to log. } 2 - \cdot 301029995 \\ \text{add log. } 3 - \cdot 477121255 \\ \hline \text{sum is log. } 6 \cdot 778151250 \end{array}$$

## EXAMPLE 6.

$$\begin{array}{l} \text{Because } 2^3 = 8, \text{ therefore} \\ \text{log. } 2 - \cdot 301029995 \frac{2}{3} \\ \text{mult. by } 3 \quad \quad \quad 3 \\ \hline \text{gives log. } 8 \cdot 903089987 \end{array}$$

## EXAMPLE 7.

$$\begin{array}{l} \text{Because } 3^2 = 9, \text{ therefore} \\ \text{log. } 3 - \cdot 477121254 \frac{7}{10} \\ \text{mult. by } 2 \quad \quad \quad 2 \\ \hline \text{gives log. } 9 \cdot 954242509 \end{array}$$

## EXAMPLE 8.

$$\begin{array}{l} \text{Because } \frac{10}{2} = 5, \text{ therefore} \\ \text{from log. } 10 \cdot 1000000000 \\ \text{take log. } 2 \cdot 301029995 \frac{2}{3} \\ \hline \text{leaves log. } 5 \cdot 698970004 \frac{1}{3} \end{array}$$

## EXAMPLE 9.

$$\begin{array}{l} \text{Because } 3 \times 4 = 12, \text{ therefore} \\ \text{to log. } 3 - \cdot 477121255 \\ \text{add log. } 4 - \cdot 602059991 \\ \hline \text{gives log. } 12 \cdot 1079181246 \end{array}$$

And thus, computing, by this general rule, the logarithms to the other prime numbers 7, 11, 13, 17, 19, &c., and then using composition and division, we may easily find as many logarithms as we please, or may speedily examine any logarithm in the table\*.

\* There are, besides these, many other ingenious methods, which later writers have discovered for finding the logarithms of numbers, in a much easier way than by the original inventor; but, as they cannot be understood without a knowledge of some of the higher branches of the mathematics, it is thought proper to omit them, and to refer the reader to those works which are written expressly on the subject.

It would likewise much exceed the limits of this compendium, to point out all the peculiar artifices that are made use of for constructing an entire table of these numbers; such as those of Gardiner, Sherwin, and others, who have treated on this subject; but any information of this kind, which the learner may wish to obtain, may be found in my Tables, before mentioned.

*Description and Use of the TABLE of LOGARITHMS.*

HAVING explained the method of making a table of the logarithms of numbers, greater than unity; the next thing to be done is, to shew how the logarithms of fractional quantities may be found. And, in order to this, it may be observed, that as in the former case a geometric series is supposed to increase towards the left, from unity, so in the latter case it is supposed to decrease towards the right hand, still beginning with unit; as exhibited in the general description, page 160; where the indices being made negative, still shew the logarithms to which they belong. Whence it appears, that as + 1 is the log. of 10, so - 1 is the log. of  $\frac{1}{10}$  or .1; and as + 2 is the log. of 100, so - 2 is the log. of  $\frac{1}{100}$  or .01: and so on.

Hence it appears in general, that all numbers which consist of the same figures, whether they be integral, or fractional, or mixed, will have the decimal parts of their logarithms the same, but differing only in the index, which will be more or less, and positive or negative, according to the place of the first figure of the number.

Thus, the logarithm of 2651 being 3.423410, the log. of  $\frac{1}{2651}$ , or  $\frac{1}{26510}$ , or  $\frac{1}{265100}$ , &c, part of it; will be as follows:

Numbers.	Logarithms.
2 6 5 1	3 .4 2 3 4 1 0
2 6 5 .1	2 .4 2 3 4 1 0
2 6 .5 1	1 .4 2 3 4 1 0
.2 6 5 1	0 .4 2 3 4 1 0
.2 6 5 1	-1 .4 2 3 4 1 0
.0 2 6 5 1	-2 .4 2 3 4 1 0
.0 0 2 6 5 1	-3 .4 2 3 4 1 0

From this it also appears, that the index, or characteristic, of any logarithm, is always less by 1 than the number of integer figures which the natural number consists of; or it is equal to the distance of the first figure from the place of units, or first place of integers, whether on the left, or on the right of it: and this index is constantly to be placed on the left-hand side of the decimal part of the logarithm.

When there are integers in the given number, the index is always affirmative; but when there are no integers, the index is negative, and is to be marked by a short line drawn before it, or else above it. Thus,

A number having 1, 2, 3, 4, 5, &c, integer places, the index of its log. is 0, 1, 2, 3, 4, &c, or is less than those places.

And

And a decimal fraction having its first figure in the 1st, 2d, 3d, 4th, &c, place of the decimals, has always  $-1$ ,  $-2$ ,  $-3$ ,  $-4$ , &c, for the index of its logarithm.

It may also be observed, that though the indices of fractional quantities are negative, yet the decimal parts of their logarithms are always affirmative. And the negative mark ( $-$ ) may be set either before the index or over it.

#### I. TO FIND, IN THE TABLE, THE LOGARITHM TO ANY NUMBER \*.

1. If the given Number be less than 100, or consist of only two figures, its log. is immediately found by inspection in the first page of the table, which contains all numbers from 1 to 100, with their logs. and index immediately annexed in the next column.

So the log. of 5 is 0.698970. The log. of 23 is 1.361728. The log. of 50 is 1.698970. And so on.

2. If the Number be more than 100 but less than 10000; the decimal part of the logarithm is found, by inspection in the other pages of the table, standing against the given number, in this manner; viz. the first three figures of the given number in the first column of the page, and the fourth figure one of those along the top line of it; then in the angle of meeting are the last four figures of the logarithm, and the first two figures of the same at the beginning of the same line in the second column of the page: to which is to be prefixed the proper index, which is always 1 less than the number of integer figures.

So the logarithm of 251 is 2.399674, that is, the decimal .399674 found in the table, with the index 2 prefixed, because the given number contains three integers. And the log. of 34.09 is 1.532627, that is, the decimal .532627 found in the table, with the index 1 prefixed, because the given number contains two integers.

3. But if the given Number contain more than four figures; take out the logarithm of the first four figures by inspection in the table, as before, as also the next greater logarithm, subtracting the one logarithm from the other, as also their corresponding numbers the one from the other. Then say,

As the difference between the two numbers,

Is to the difference of their logarithms,

So is the remaining part of the given number,

To the proportional part of the logarithm.

---

\* See the table of Logarithms, after the Geometry, at the end of the volume.

Which part being added to the less logarithm, before taken out, gives the whole logarithm sought, very nearly.

## EXAMPLE.

To find the logarithm of the number 34.0926.

The log. of 340900, as before, is 532627.

And log. of 341000 - is 532754.

The diffs. are 100 and 127

Then, as  $100 : 127 :: 26 : 33$ , the proportional part.

This added to - - - 532627, the first log.

Gives, with the index, 1.532660 for the log. of 34.0926.

4. If the number consist both of integers and fractions, or is entirely fractional; find the decimal part of the logarithm the same as if all its figures were integral; then this, having prefixed to it the proper index, will give the logarithm required.

5. And if the given number be a proper vulgar fraction; subtract the logarithm of the denominator from the logarithm of the numerator, and the remainder will be the logarithm sought; which, being that of a decimal fraction, must always have a negative index.

6. But if it be a mixed number; reduce it to an improper fraction, and find the difference of the logarithms of the numerator and denominator, in the same manner as before.

## EXAMPLES.

1. To find the log. of $\frac{37}{94}$ .	2. To find the log of $17\frac{14}{23}$ .
Log. of 37 - 1.568202	First, $17\frac{14}{23} = \frac{405}{23}$ . Then,
Log. of 94 - 1.973128	Log. of 405 - 2.607455
Dif. log. of $\frac{37}{94}$ - 1.595074	Log. of 23 - 1.361728
Where the index 1 is negative.	Dif. log. of $17\frac{14}{23}$ 1.245727

## II. TO FIND THE NATURAL NUMBER TO ANY GIVEN LOGARITHM.

THIS is to be found in the tables by the reverse method to the former, namely, by searching for the proposed logarithm among those in the table, and taking out the corresponding number by inspection, in which the proper number of integers are to be pointed off, viz. 1 more than the index. For, in finding the number answering to any given logarithm, the index always shews how far the first figure must

must be removed from the place of units, viz. to the left hand, or integers, when the index is affirmative; but to the right hand, or decimals, when it is negative.

## EXAMPLES.

So, the number to the log.  $1\cdot532882$  is 34.11.

And the number of the log.  $1\cdot532882$  is .3411.

But if the logarithm cannot be exactly found in the table; take out the next greater and the next less, subtracting the one of these logarithms from the other, as also their natural numbers the one from the other, and the less logarithm from the logarithm proposed. Then say,

As the difference of the first or tabular logarithms,

Is to the difference of their natural numbers,

So is the differ. of the given log. and the least tabular log.

To their corresponding numeral difference.

Which being annexed to the least natural number above taken, gives the natural number sought, corresponding to the proposed logarithm.

## EXAMPLE.

So, to find the natural number answering to the given logarithm  $1\cdot532708$ .

Here the next greater and next less tabular logarithms, with their corresponding numbers, &c, are as below:

Next greater 532754 its num. 341000; given log. 532708

Next less 532627 its num. 340900; next less 532627

Differences	<u>127</u>	<u>—</u>	<u>100</u>	<u>—</u>	<u>81</u>
-------------	------------	----------	------------	----------	-----------

Then, as  $127 : 100 :: 81 : 64$  nearly the numeral differ.

Therefore 34.0964 is the number sought, marking off two integers, because the index of the given logarithm is 1.

Had the index been negative, thus  $1\cdot532708$ , its corresponding number would have been .340964, wholly decimal.

## III. MULTIPLICATION BY LOGARITHMS.

## RULE.

TAKE out the logarithms of the factors from the table, then add them together, and their sum will be the logarithm of the product required. Then by means of the table, take out the natural number, answering to the sum, for the product sought.

Observing to add what is to be carried from the decimal part of the logarithm to the affirmative index or indices, or else subtract it from the negative.

Also, adding the indices together when they are of the same kind, both affirmative or both negative; but subtracting the less from the greater, when the one is affirmative and the other negative, and prefixing the sign of the greater to the remainder.

## EXAMPLES.

1. To multiply 23·14 by  
5·062.

Numbers.	Logs.
23·14	- 1·364363
5·062	- 0·704322
Product 117·1347	2·068685

2. To multiply 2·581926  
by 3·457291.

Numbers.	Logs.
2·581926	- 0·411944
3·457291	- 0·538736
Product 8·92648	0·950680

3. To mult. 93·02, and 597·16,  
and ·0314728 all together.

Numbers.	Logs.
3·902	- 0·591287
597·16	- 2·776091
·0314728	- 2·497935
Prod. 73·3333	- 1·865313

4. To mult. 3·586, and 2·1046,  
and 0·8372, and 0·0294 all  
together.

Numbers.	Logs.
3·586	- 0·554610
2·1046	- 0·323170
0·8372	- 1·922829
0·0294	- 2·468347

Here the — 2 cancels the 2,  
and the 1 to carry from the  
decimals is set down.

Prod. 0·1857618 - 1·268958

Here the 2 to carry cancels  
the — 2, and there remains the  
the -- 1 to set down.

## DIVISION BY LOGARITHMS.

## RULE.

FROM the logarithm of the dividend subtract the logarithm of the divisor, and the number answering to the remainder will be the quotient required.

Observing to change the sign of the index of the divisor, from affirmative to negative, or from negative to affirmative ; then take the sum of the indices if they be of the same name, or their difference when of different signs, with the sign of the greater, for the index to the logarithm of the quotient.

And also, when 1 is borrowed, in the left-hand place of the decimal part of the logarithm, add it to the index of the divisor when that index is affirmative, but subtract it when negative ; then let the index arising from thence be changed, and worked with as before.

## EXAMPLES.

i. To divide 24163 by 4567. 2. To divide 37·149 by 523·76.

Numbers.	Logs.	Numbers.	Logs.
Dividend 24163 -	4·383151	Dividend 37·149 -	1·569947
Divisor 4567 -	3·659631	Divisor 523·76 -	2·719132
Quot. 5·29078	0·723520	Quot. ·0709275	-2·850815

3. Divide ·06314 by ·007241. 4. To divide ·7438 by 12·9476.

Numbers.	Logs.	Numbers.	Logs.
Divid. ·06314 -	2·800305	Divid. ·7438 -	1·871456
Divisor ·007241 -	3·859799	Divisor 12·9476	1·112189
Quot. 8·71979	0·940506	Quot. ·057447	-2·759267

Here 1 carried from the decimals to the -3, makes it -2, which taken from the other -2, leaves 0 remaining.

Here the 1 taken from the -1, makes it become -2, to set down.

*Note.* As to the Rule-of-Three, or Rule of Proportion, it is performed by adding the logarithms of the 2d and 3d terms, and subtracting that of the first term from their sum.

## INVOLUTION BY LOGARITHMS.

## R U L E .

TAKE out the logarithm of the given number from the table.

Multiply the log. thus found, by the index of the power proposed.

Find the number answering to the product, and it will be the power required.

*Note.* In multiplying a logarithm with a negative index, by an affirmative number, the product will be negative.

But what is to be carried from the decimal part of the logarithm, will always be affirmative.

And therefore their difference will be the index of the product, and is always to be made of the same kind with the greater.

## E X A M P L E S .

1. To square the number 2.5791.	2. To find the cube of 3.07146.
Numb.      Log. Root 2.5791 - - 0.411468	Numb.      Log. Root 3.07146 - - 0.487345
The index - - 2	The index - - 3
Power 6.65174	Power 28.9758
0.822936	1.462035
3. To raise .09163 to the 4th power.	4. To raise 1.0045 to the 365th power.
Numb.      Log. Root .09163 - - 2.962038	Numb.      Log. Root 1.0045 - - 0.001950
The index - - 4	The index - - 365
Pow. .000070494 - 5.848152	9750 11700 5850
Here, 4 times the negative index being - 8, and 3 to carry, the difference - 5 is the index of the product.	Power 5.14932 - 711750

## EVOLUTION BY LOGARITHMS.

TAKE the log. of the given number out of the table.  
 Divide the log. thus found, by the index of the root.  
 Then the number answering to the quotient, will be the root.

*Note.* When the index of the logarithm, to be divided, is negative, and does not exactly contain the divisor, without some remainder, increase the index by such a number as will make it exactly divisible by the index, carrying the units borrowed, as so many tens, to the left-hand place of the decimal; and then divide as in whole numbers.

Ex. 1. To find the square root of 365. Ex. 2 To find the 3d root of 12345.

Numb.	Log.	Numb.	Log.
Power 365 2)	2.562293	Power 12345 3)	4.091491
Root 19.10496	1.281146 $\frac{1}{2}$	Root 23.1116	1.363830 $\frac{1}{2}$

Ex. 3. To find the 10th root of 2. Ex. 4. To find the 365th root of 1.045.

Numb.	Log.	Numb.	Log.
Power 2 - 10)	0.301030	Power 1.045 365)	0.019116
Root 1.071773	0.030103	Root 1.000121	0.000052 $\frac{1}{2}$

Ex. 5. To find  $\sqrt{.093}$ .

Numb.	Log.	Numb.	Log.
Power .093 2) - 2.968483		Power .00048 3) - 4.681241	
Root .304959 - 1.484241 $\frac{1}{2}$		Root .0782973 - 2.893747	

Here the divisor 2 is contained exactly once in the negative index - 2, and therefore the index of the quotient is - 1.

Here, the divisor 3 not being exactly contained in - 4, it is augmented by 2, to make up 6, in which the divisor is contained just 2 times; then the 2, thus borrowed, being carried to the decimal figure 6, makes 26, which divided by 3, gives 8, &c.

Ex. 7. To find  $\frac{1}{3}\sqrt{\frac{3}{7}} \times .001\sqrt[3]{\frac{9}{7}}$ .

Ex. 8. To find  $\frac{2\frac{3}{7}\sqrt{\frac{11}{27}} \times .02\sqrt[5]{13\frac{3}{37}}}{7\frac{8}{11}\sqrt[3]{37\frac{1}{3}} \times .09\sqrt[4]{\frac{17}{319}}}$ .

Ex. 9. As  $\sqrt[7]{7} : \sqrt[3]{7\frac{11}{4594}} :: \sqrt[5]{4\frac{1}{8}\sqrt[3]{637}} : ?$

Ex. 10. As  $\sqrt[4]{7\frac{1}{1079}} : (\frac{1}{1079})^3 :: \sqrt[4]{12\frac{1}{476}} : ?$

# A L G E B R A.

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## DEFINITIONS AND NOTATION.

1. ALGEBRA is the art of computing by symbols. It is sometimes also called Analysis; and is a general kind of arithmetic, or universal way of computation.

2. In this science, quantities of all kinds are represented by the letters of the alphabet. And the operations to be performed with them, as addition or subtraction, &c, are denoted by certain simple characters, instead of being expressed by words at length.

3. In algebraical questions, some quantities are known or given, viz. those whose values are known: and others unknown, or are to be found out, viz. those whose values are not known. The former of these are represented by the leading letters of the alphabet,  $a, b, c, d, \dots$ ; and the latter, or unknown quantities, by the final letters,  $z, y, x, u, \dots$ .

4. The characters used to denote the operations, are chiefly the following:

- $+$  signifies addition, and is named *plus*.
- $-$  signifies subtraction, and is named *minus*.
- $\times$  or . signifies multiplication, and is named *into*.
- $\div$  signifies division, and is named *by*.
- $\sqrt{\phantom{x}}$  signifies the square root;  $\sqrt[3]{\phantom{x}}$  the cube root;  $\sqrt[n]{\phantom{x}}$  the  $n$ th root.

$:::$  signifies proportion.

$=$  signifies equality, and is named *equal to*.  
And so on for other operations.

Thus  $a + b$  shews, that the number represented by  $b$  is to be added to that represented by  $a$ .

$a - b$  shews, that the number represented by  $b$  is to be subtracted from that represented by  $a$ .

$a \times b$  represents the difference of  $a$  and  $b$ , when it is not known which is the greater.

$ab$ , or  $a \times b$ , or  $a.b$ , denotes the product, by multiplication, of the numbers represented by  $a$  and  $b$ .

$a \div b$ , or  $\frac{a}{b}$ , shews that the number represented by  $a$  is to be divided by that which is represented by  $b$ .

$\frac{a}{b}$  is the reciprocal of  $\frac{b}{a}$ , and  $\frac{1}{a}$  the reciprocal of  $a$ .

$a : b :: c : d$ , denotes that  $a$  is in the same proportion to  $b$ , as  $c$  is to  $d$ .

$x = a - b + c$  is an equation, shewing that  $x$  is equal to the difference of  $a$  and  $b$ , added to the quantity  $c$ .

$\sqrt{a}$ , or  $a^{\frac{1}{2}}$ , is the square root of  $a$ ;  $\sqrt[3]{a}$ , or  $a^{\frac{1}{3}}$ , is the cube root of  $a$ ; and  $\sqrt[3]{a^2}$  or  $a^{\frac{2}{3}}$  is the cube root of the square of  $a$ ; and  $\sqrt[m]{a}$ , or  $a^{\frac{1}{m}}$ , is the  $m$ th root of  $a$ ; and  $\sqrt[m]{a^n}$  or  $a^{\frac{n}{m}}$  is the  $n$ th power of the  $m$ th root of  $a$ , or it is  $a$  to the  $\frac{n}{m}$  power.

$a^2$  is the square of  $a$ ;  $a^3$  the cube of  $a$ ;  $a^4$  the fourth power of  $a$ ; and  $a^m$  the  $m$ th power of  $a$ .

$\overline{a+b} \times c$ , or  $(a+b)c$ , is the product of the compound quantity  $a+b$  multiplied by the simple quantity  $c$ . Using the bar  $\overline{\quad}$ , or the parenthesis  $(\ )$  as a vinculum, to connect several quantities into one.

$\overline{a+b \div a-b}$ , or  $\frac{a+b}{a-b}$ , expressed like a fraction, is the quotient of  $a+b$  divided by  $a-b$ .

$\sqrt{ab+cd}$ , or  $(ab+cd)^{\frac{1}{2}}$ , is the square root of the compound quantity  $ab+cd$ . And  $c\sqrt{ab+cd}$ , or  $c(ab+cd)^{\frac{1}{2}}$ , denotes the product of  $c$  into the square root of the compound quantity  $ab+cd$ .

$\overline{a+b-c}^3$ , or  $(a+b-c)^3$ , is the cube, or third power, of the compound quantity  $a+b-c$ .

$5a$  denotes that the quantity  $a$  is to be taken 5 times, and  $7 \cdot (b+c)$  is 7 times  $b+c$ . And these numbers, 5 or 7, shewing how often the quantities are to be taken, or multiplied, are called Co-efficients.

Also  $\frac{3}{4}x$  denotes that  $x$  is multiplied by  $\frac{3}{4}$ ; thus  $\frac{3}{4} \times x$  or  $\frac{3}{4}x$ .

5. Like Quantities, are those which consist of the same letters, and powers. As  $a$  and  $3a$ ; or  $2ab$  and  $4ab$ ; or  $3a^2bc$  and  $-5a^2bc$ .

6. Unlike Quantities, are those which consist of different letters, or different powers. As  $a$  and  $b$ ; or  $2a$  and  $a^2$ ; or  $3ab^2$  and  $3abc$ .

7. Simple

7. Simple Quantities, are those which consist of one term only. As  $3a$ , or  $5ab$ , or  $6abc^2$ .

8. Compound Quantities, are those which consist of two or more terms. As  $a + b$ , or  $2a - 3c$ , or  $a + 2b - 3c$ .

9. And when the compound quantity consists of two terms, it is called a Binomial, as  $a + b$ ; when of three terms, it is a Trinomial, as  $a + 2b - 3c$ ; when of four terms, a Quadrinomial, as  $2a - 3b + c - 4d$ ; and so on. Also, a Multinomial or Polynomial, consists of many terms.

10. A Residual Quantity, is a binomial having one of the terms negative. As  $a - 2b$ .

11. Positive or Affirmative Quantities, are those which are to be added, or have the sign  $+$ . As  $a$  or  $+a$ , or  $ab$ : for when a quantity is found without a sign, it is understood to be positive, or to have the sign  $+$  prefixed.

12. Negative Quantities, are those which are to be subtracted. As  $-a$ , or  $-2ab$ , or  $-3ab^2$ .

13. Like Signs, are either all positive ( $+$ ), or all negative ( $-$ ).

14. Unlike Signs, are when some are positive ( $+$ ), and others negative ( $-$ ):

15. The Co-efficient of any quantity, as shewn above, is the number prefixed to it. As  $3$ , in the quantity  $3ab$ .

16. The Power of a quantity ( $a$ ), is its square ( $a^2$ ), or cube ( $a^3$ ), or biquadrate ( $a^4$ ), &c; called also, the 2d power, or 3d power, or 4th power, &c.

17. The Index or Exponent, is the number which denotes the power or root of a quality. So  $2$  is the exponent of the square or second power  $a^2$ ; and  $3$  is the index of the cube or 3d power; and  $\frac{1}{2}$  is the index of the square root,  $a^{\frac{1}{2}}$  or  $\sqrt{a}$ ; and  $\frac{1}{3}$  is the index of the cube root,  $a^{\frac{1}{3}}$  or  $\sqrt[3]{a}$ .

18. A Rational Quantity, is that which has no radical sign ( $\sqrt{ }$ ) or index annexed to it. As  $a$ , or  $3ab$ .

19. An Irrational Quantity, or Surd, is that which has not an exact root, or is expressed by means of the radical sign  $\sqrt{ }$ . As  $\sqrt{2}$ , or  $\sqrt{a}$ , or  $\sqrt[3]{a^2}$ , or  $ab^{\frac{1}{2}}$ .

20. The Reciprocal of any quantity, is that quantity inverted, or unity divided by it. So, the reciprocal of  $a$ , or  $\frac{a}{1}$ , is  $\frac{1}{a}$ , and the reciprocal of  $\frac{a}{b}$  is  $\frac{b}{a}$ .

21. The letters by which any simple quantity is expressed, may be ranged according to any order at pleasure. So the product of  $a$  and  $b$ , may be either expressed by  $ab$ , or  $ba$ ; and the product of  $a$ ,  $b$ , and  $c$ ; by either  $abc$ , or  $acb$ , or  $bac$ , or  $bca$ , or  $cab$ , or  $cba$ ; as it matters not which quantities are placed or multiplied first. But it will be sometimes found convenient, in long operations, to place the several letters according to their order in the alphabet, as  $abc$ , which order also occurs most easily or naturally to the mind.

22. Likewise, the several members, or terms, of which a compound quantity is composed, may be disposed in any order at pleasure, without altering the value of the significance of the whole. Thus,  $3a - 2b + 4abc$  may also be written  $3a + 4abc - 2ab$ , or  $4abc + 3a - 2ab$ , or  $-2ab + 3a + 4abc$ , &c; for all these represent the same thing, namely, the quantity which remains, when the quantity or term  $2ab$  is subtracted from the sum of the terms or quantities  $3a$  and  $4abc$ . But it is most usual and natural, to begin with a positive term, and with the first letters of the alphabet.

#### SOME EXAMPLES FOR PRACTICE,

In finding the numeral values of various expressions, or combinations, of quantities.

Supposing  $a = 6$ , and  $b = 5$ , and  $c = 4$ , and  $d = 1$ , and  $e = 0$ . Then

$$1. \text{ Will } a^2 + 3ab - c^2 = 36 + 90 - 16 = 110.$$

$$2. \text{ And } 2a^3 - 3a^2b + c^3 = 432 - 540 + 64 = -44.$$

$$3. \text{ And } a^2 \times \overline{a+b} - 2abc = 36 \times 11 - 240 = 156.$$

$$4. \text{ And } \frac{a^3}{a+3c} + c^2 = \frac{216}{18} + 16 = 12 + 16 = 28.$$

$$5. \text{ And } \sqrt{2ae+c^2} \text{ or } \sqrt{2ac+c^2}^{\frac{1}{2}} = \sqrt{64} = 8.$$

$$6. \text{ And } \sqrt{c \times \frac{2bc}{\sqrt{2ac+c^2}}} = 2 + \frac{40}{8} = 7.$$

$$7. \text{ And } \frac{a^2 - \sqrt{b^2 - ac}}{2a - \sqrt{b^2 + ac}} = \frac{36 - 1}{12 - 7} = \frac{35}{5} = 7.$$

$$8. \text{ And } \sqrt{b^2 - ac} + \sqrt{2ac + c^2} = 1 + 8 = 9.$$

$$9. \text{ And } \sqrt{b^2 - ac} + \sqrt{2ac + c^2} = \sqrt{25 - 24 + 8} = 3.$$

$$10. \text{ And } a^2b + c - d =$$

$$11. \text{ And } 5ab - 10b^2 + e =$$

$$12. \text{ And }$$

12. And  $\frac{a^2b}{c} \times d =$

13. And  $\frac{a+b}{c} \times \frac{b}{d} =$

14. And  $\frac{a+b}{c} - \frac{a-b}{d} =$

15. And  $\frac{a^2b}{c} + e =$

16. And  $\frac{a^2b}{c} \times e =$

17. And  $\overline{b-c} \times \overline{d-e} =$

18. And  $\overline{a+b} - \overline{c-d} =$

19. And  $\overline{a+b} - c - d =$

20. And  $a^2c \times d^3 =$

21. And  $acd - d =$

22. And  $a^2e + b^2e + d =$

23. And  $\frac{b-c}{d-e} \times \frac{a+b}{c-d} =$

24. And  $\sqrt{a^2 + b^2} - \sqrt{a - b} =$

25. And  $3ac^2 + \sqrt[3]{a^3 - b^3} =$

26. And  $4a^2 - 3a\sqrt{a^2 - \frac{2}{3}ab} =$

## ADDITION.

ADDITION, in Algebra, is the connecting the quantities together by their proper signs, and incorporating or uniting into one term or sum, such as are similar, and can be united. As  $3a + 2b - 2a = a + 2b$ , the sum.

The rule of addition in algebra, may be divided into three cases: one, when the quantities are like, and their signs like also; a second, when the quantities are like, but their signs unlike; and the third, when the quantities are unlike. Which are performed as follows\*.

## CASE

\* The reasons on which these operations are founded, will readily appear, by a little reflection on the nature of the quantities to be

## CASE I.

*When the Quantities are Like, and have Like Signs:*

FIRST set down the common sign; after which set the sum of the co-efficients, found by adding them together; to which annex the common letter or letters of the like quantities.

---

be added, or collected together. For, with regard to the first example, where the quantities are  $3a$  and  $5a$ , whatever  $a$  represents in the one term, it will represent the same thing in the other; so that 3 times any thing and 5 times the same thing, collected together, must needs make 8 times that thing. As if  $a$  denote a shilling; then  $3a$  is 3 shillings, and  $5a$  is 5 shillings, and their sum 8 shillings. In like manner,  $-2ab$  and  $-7ab$ , or  $-2$  times any thing, and  $-7$  times the same thing, make  $-9$  times that thing.

As to the second case, in which the quantities are like, but the signs unlike; the reason of its operation will easily appear, by reflecting, that addition means only the uniting of quantities together by means of the arithmetical operations denoted by their signs  $+$  and  $-$ , or of addition and subtraction; which being of contrary or opposite natures, the one co-efficient must be subtracted from the other, to obtain the incorporated or united mass.

As to the third case, where the quantities are unlike, it is plain that such quantities cannot be united into one, or otherwise added, than by means of their signs: thus, for example, if  $a$  be supposed to represent a crown, and  $b$  a shilling; then the sum of  $a$  and  $b$  can be neither  $2a$  nor  $2b$ , that is neither 2 crowns nor 2 shillings, but only 1 crown plus 1 shilling, that is  $a + b$ .

In this rule, the word *addition* is not very properly used; being much too scanty to express the operation here performed. The business of this operation is to incorporate into one mass, or algebraic expression, different algebraic quantities, as far as an actual incorporation or union is possible; and to retain the algebraic marks for doing it, in cases where the former is not possible. When we have several quantities, some affirmative and some negative; and the relation of these quantities can in the whole or in part be discovered; such incorporation of two or more quantities into one, is plainly effected by the foregoing rules.

It may seem a paradox, that what is called addition in algebra, should sometimes mean addition, and sometimes subtraction. But the paradox wholly arises from the scantiness of the name given to the algebraic process; from employing an old term in a new and more enlarged sense. Instead of addition, call it incorporation, or union, or striking a balance, or any name to which a more extensive idea may be annexed, than that which is usually implied by the word addition; and the paradox vanishes.

Thus,

Thus,  $3a$  added to  $5a$ , makes  $8a$ .

And  $-2ab$  added to  $-7ab$ , makes  $-9ab$ .

And  $5a + 7b$  added to  $7a + 3b$ , makes  $12a + 10b$ .

## OTHER EXAMPLES FOR PRACTICE.

$5 a$	$- 6 bx$	$8 bxy$
$7 a$	$- 3 bx$	$7 bxy$
$8 a$	$- 2 bx$	$3 bxy$
$10 a$	$- 7 bx$	$4 bxy$
$2 a$	$- bx$	$5 bxy$
$a$	$- 5 bx$	$bxy$
<hr/>	<hr/>	<hr/>
$33 a$	$- 24 bx$	$28 bxy$
<hr/>	<hr/>	<hr/>

$2 y$	$5 x^2 + 5 xy$	$7 ax - 4y$
$5 y$	$3 x^2 + 2 xy$	$8 ax - 3y$
$7 y$	$x^2 + 3 xy$	$6 ax - 2y$
$4 y$	$7 x^2 + 8 xy$	$4 ux - 3y$
$3 y$	$x^2 + xy$	$2 ax - 2y$
<hr/>	<hr/>	<hr/>
$21 y$	$17 x^2 + 19 xy$	$27 ax - 14y$
<hr/>	<hr/>	<hr/>

$6 xy$	$- 2 y^2$	$5 a - 4 b$
$15 xy$	$- 8 y^2$	$7 a - 6 b$
$2 xy$	$- 7 y^2$	$4 a - 3 b$
$7 xy$	$- y^2$	$2 a - 8 b$
$1\frac{1}{2} xy$	$- 6 y^2$	$6 a - b$
$\frac{1}{2} xy$	$- y^2$	$3 a - 2 b$
<hr/>	<hr/>	<hr/>
<hr/>	<hr/>	<hr/>

$20 - 15 x^{\frac{1}{2}}$	$- 2 xy$	$7 xy - 5 x + 3 ab$
$35 - 13 x^{\frac{1}{2}}$	$- 4 xy$	$3 xy - x + 2 ab$
$18 - 12 x^{\frac{1}{2}}$	$- 3 xy$	$2 xy - 3 x + 2 ab$
$12 - 14 x^{\frac{1}{2}}$	$- 8 xy$	$2 xy - 4 x + 8 ab$
$10 - 28 x^{\frac{1}{2}}$	$- 2 xy$	$5 xy - 3 x + ab$
<hr/>	<hr/>	<hr/>
<hr/>	<hr/>	<hr/>

## CASE II.

*When the Quantities are Like, but have Unlike Signs:*

ADD all the affirmative co-efficients into one sum, and all the negative ones into another, when there are several of a kind.

Subtract the less sum, or the less co-efficient, from the greater, and to the difference prefix the sign of the greater, and subjoin the common quantity. —

So  $+ 5a$  and  $- 3a$ , united, make  $+ 2a$ .

And  $- 5a$  and  $+ 3a$ , united, make  $- 2a$ .

## OTHER EXAMPLES FOR PRACTICE.

$$\begin{array}{rcl}
 -3a & +8ax^2 & +6x^3 + 8y \\
 +7a & +7ax^2 & -3x^3 + 7y \\
 +8a & -3ax^2 & -13x^3 + 8y \\
 -a & -4ax^2 & +2x^3 - 3y \\
 -2a & +4ax^2 & +x^3 - y \\
 \hline
 +9a & +12ax^2 & -7x^3 + 19y
 \end{array}$$

$$\begin{array}{rcl}
 -2a^2 & +8b^2y^3 & -3ab + 7 \\
 -3a^2 & +6b^2y^3 & +3ab - 10 \\
 -8a^2 & -10b^2y^3 & +3ab - 6 \\
 +10a^2 & -20b^2y^3 & -ab + 2 \\
 +13a^2 & -b^2y^3 & -2ab + 11 \\
 \hline
 \hline
 \end{array}$$

$$\begin{array}{rcl}
 -2ax^{\frac{1}{2}} & -6\sqrt{ax} & -2y + 2ax^{\frac{1}{2}} \\
 +ax^{\frac{1}{2}} & +2\sqrt{ax} & +y + ax^{\frac{1}{2}} \\
 -3ax^{\frac{1}{2}} & -6\sqrt{ax} & -7y - 3ax^{\frac{1}{2}} \\
 +7ax^{\frac{1}{2}} & +10\sqrt{ax} & +5y + 3ax^{\frac{1}{2}}
 \end{array}$$

## CASE III.

*When the Quantities are Unlike.*

HAVING collected together all the like quantities, as in the two foregoing cases, set down those that are unlike, one after another, with their proper signs.

## EXAMPLES.

$5xy$	$2xy - 10x^2$	$2ax - 150 + 2x^{\frac{1}{2}}$
$4ax$	$-3x^4 + xy$	$3x^2 + 2ax + 6x^2$
$-xy$	$-8x^2 - xy$	$5xy - 3x^{\frac{1}{2}} + 50$
$-4ax$	$-xy + 9x^2$	$\sqrt{x + 100} - 5x^2$
<hr/>	<hr/>	<hr/>
$4xy$	$xy - 12x^2$	$4ax + 4x^2 + 5xy$
<hr/>	<hr/>	<hr/>
$6x^2y^2$	$12ax - x^2$	$6 + 10\sqrt{ax} - 3y$
$-4x^2y$	$4ax + xy$	$x + 4\sqrt{xy} + 3y$
$-2axy$	$3y^2 - ax$	$y - 2\sqrt{ax} - 3y$
$-3x^2y$	$2x^2 - 24$	$20 + 3\sqrt{ax} - 3y$
<hr/>	<hr/>	<hr/>
<hr/>	<hr/>	<hr/>
$3x^2y$	$2\sqrt{x} - 8y$	$a^2 - 8 + x^{\frac{1}{2}} - 2$
$-2xy^2$	$3\sqrt{xy} + 10x$	$a - 10 + a^2 - x$
$-3y^2x$	$2x + \sqrt{x} + y$	$x^2 - a^2 + 8 - 4$
$-8x^2y$	$-8 + \sqrt{xy}$	$10 - a - x^2 - y$
<hr/>	<hr/>	<hr/>
<hr/>	<hr/>	<hr/>

Add  $a + b$  and  $3a - 5b$  together.

Add  $5a - 8x$  and  $3a - 4x$  together.

Add  $6x - 5b + a + 8$  to  $-5a - 4x + 4b - 3$ .

Add  $a + 2b - 3c - 10$  to  $3b - 4a + 5c + 10$  and  $5b - c$ .

Add  $a + b$  and  $a - b$  together.

Add  $3a + b - 10$  to  $c - d - a$  and  $-4c + 2a - 3b - 7$ .

Add  $3a^2 + b^2 - c$  to  $2ab - 3a^2 + bc - b$ .

Add  $a^3 + b^2c - b^2$  to  $ab^2 - abc + b^2$ .

Add  $9a - 8b + 10x - 6d - 7c + 50$  to  $2x - 3a - 5c + 4b + 6d - 10$ .

## SUBTRACTION.

SET down in one line the first quantities from which the subtraction is to be made; and underneath them place all the other quantities composing the subtrahend; ranging the like quantities under each other, as in Addition.

Then change all the signs (+ and -) of the lower line, or conceive them to be changed; after which, collect all the terms together as in the cases of Addition\*.

## EXAMPLES.

$$\begin{array}{r} 5a^2 - 2b \\ 2a^2 - 5b \\ \hline 3a^2 + 3b \end{array} \quad \begin{array}{r} 6x^2 - 8y + 3 \\ 2x^2 + 9y - 2 \\ \hline 4x^2 - 17y + 5 \end{array} \quad \begin{array}{r} 5xy - 2 + 8x - y \\ 3xy - 8 - 8x - 3y \\ \hline 2xy + 6 + 16x + 2y \end{array}$$

$$\begin{array}{r} 5xy - 3 \\ - xy + 8 \\ \hline 4xy - 16 \end{array} \quad \begin{array}{r} 2y^2 - y - 1 \\ y^2 + y + 1 \\ \hline y^2 - 2y - 2 \end{array} \quad \begin{array}{r} - 10 - 8x - 3xy \\ xy - 7x + 3 - 4ay \\ \hline - 13 - x - 4xy + 4ay \end{array}$$

$$\begin{array}{r} 5x^2y - 8 \\ - 3x^2y + 1 \\ \hline \end{array} \quad \begin{array}{r} 4\sqrt{xy} - x\sqrt{xy} \\ 2\sqrt{xy} + 2 + xy \\ \hline \end{array} \quad \begin{array}{r} 5x^2 + \sqrt{x} - 8 - 4b \\ 6x^2 - 10 + 4b - x^{\frac{1}{2}} \\ \hline \end{array}$$

\* This rule is founded on the consideration, that addition and subtraction are opposite to each other in their nature and operation, as are the signs + and -, by which they are expressed and represented. So that, since to unite a negative quantity with a positive one of the same kind, has the effect of diminishing it, or subducting an equal positive one from it, therefore to subtract a positive (which is the opposite of uniting or adding) is to add the equal negative quantity. In like manner, to subtract a negative quantity, is the same in effect as to add or unite an equal positive one. So that, by changing the sign of a quantity from + to -, or from - to +, changes its nature from a subductive quantity to an additive one; and any quantity is in effect subtracted, by barely changing its sign.

$$\begin{array}{r} 3xy - 20 \\ 3xy - 30 \\ \hline \end{array} \quad \begin{array}{r} 4x^3 - 3(a+b) \\ 3x^2 - 8(a+b) \\ \hline \end{array} \quad \begin{array}{r} xy^3 + 10a\sqrt{(xy+10)} \\ x^2y^2 + 2a\sqrt{(xy+10)} \\ \hline \end{array}$$

From  $a + b$ , take  $a - b$ .

From  $4a + 4b$ , take  $b + a$ .

From  $4a - 4b$ , take  $3a + 5b$ .

From  $8a - 12x$ , take  $3a - 4x$ .

From  $2x - 4a - b + 5$ , take  $8 - 5b + a + 6x$ .

From  $3a + b + c - a - 10$ , take  $c + a - d$ .

From  $3a + b + c - d - 10$ , take  $b - 10 + 3a$ .

From  $2ab + b - c + bc - b$ , take  $3a^2 - c + b^2$ .

From  $a + b c + ab' - abc$ , take  $b + ab - abc$ .

From  $12x + 6a - 4b + 40$ , take  $4b - 3a + 2x + 6d - 10$ .

From  $2x - 3a + 4b + 6c - 50$ , take  $9a + x + 8b - 6c - 40$ .

From  $6a - 4b - 12c + 12x$ , take  $2x - 3a + 4b - 5c$ .

## MULTIPLICATION,

### CASE I.

*When both the Factors are Simple Quantities;*

MULTIPLY the co-efficients of the two terms together, then to the product affix all the letters in those terms, and the result will be the whole product required.

Note \*. Like signs produce +, and unlike signs -.

### EXAMPLES.

\* That like signs make +, and unlike signs -, in the product, may be shewn thus.

1. When  $+a$  is to be multiplied by  $+b$ ; this implies that  $+a$  is to be taken as many times as there are units in  $b$ ; and since the sum of any number of affirmative terms is affirmative, it follows that  $+a \times +b$  makes  $+ab$ .

2. When

## EXAMPLES.

$12a$

$3b$

$-2a$

$+4b$

$5a$

$-6x$

$-9x$

$-5b$

$\underline{36ab}$

$\underline{-8ab}$

$\underline{-30ax}$

$\underline{+45bx}$

$7ab$

$-5ac$

$6a^2x$

$5x$

$-x^2y$

$xy^2$

$-7xy$

$-xy$

$\underline{-35a^2bc}$

$\underline{30a^2x^2}$

$\underline{-x^3y^3}$

$\underline{+7x^2y^2}$

$-5ax$

$3x$

$-ax$

$-7b$

$+5xy$

$-3$

$-7xyz$

$-6ax$

$\underline{\quad\quad\quad}$

$\underline{\quad\quad\quad}$

$\underline{\quad\quad\quad}$

$\underline{\quad\quad\quad}$

## CASE II.

*When one of the Factors is a Compound Quantity;*

MULTIPLY every term of the multiplicand, or compound quantity, separately, by the multiplier, as in the former case; placing the products one after another, with the proper signs; and the result will be the whole product required.

2. When two quantities are to be multiplied together, the result will be exactly the same, in whatever order they are placed; for  $a$  times  $b$  is the same as  $b$  times  $a$ , and therefore, when  $-a$  is to be multiplied by  $+b$ , or  $+b$  by  $-a$ : this is the same thing as taking  $-a$  as many times as there are units in  $+b$ ; and since the sum of any number of negative terms is negative, it follows that  $-a \times +b$ , or  $+a \times -b$  make or produce  $-ab$ .

3. When  $-a$  is to be multiplied by  $-b$ : here  $-a$  is to be subtracted as often as there are units in  $b$ : but subtracting negatives is the same thing as adding affirmatives, by the demonstration of the rule for subtraction; consequently the product is  $b$  times  $a$ , or  $+ab$ .

Otherwise. Since  $a - a = 0$ , therefore  $(a - a) \times -b$  is also  $= 0$ , because 0 multiplied by any quantity, is still but 0; and since the first term of the product, or  $a \times -b$  is  $= -ab$ , by the second case; therefore the last term of the product, or  $-a + -b$ , must be  $+ab$ , to make the sum  $= 0$ , or  $-ab + ab = 0$ ; that is,  $-a \times -b = +ab$ .

EXAMPLES.

## EXAMPLES.

$4a - 2b$

$3a$

$\underline{12a^2 - 6ab}$

$13x - ab$

$12a$

$2x^2 + x$

$2xy$

$6xy - 8$

$2x$

$\underline{12x^2y - 16x}$

$35x - 7a$

$-x$

$12x^2 - 4y^2$

$-2x^2$

$a^2 - 2x + 6$

$xy$

$\underline{axy - 2x^2y + 6xy}$

$3y - 8 + 2xy$

$xy$

$2y^2 - 8x^2 - 7x$

$3xy^2$

## CASE III.

*When both the Factors are Compound Quantities;*

MULTIPLY every term of the multiplier into every term of the multiplicand, respectively; setting down the products one after or under another, with their proper signs; and add the several lines of products all together for the whole product required.

$x + y$

$x + y$

$x^2 + xy$

$+ xy + y^2$

$\underline{x^2 + 2xy + y^3}$

$5x + 4y$

$3x - 2y$

$15x^2 + 12xy$

$- 10xy - 8y^2$

$\underline{15x^2 + 2xy - 8y^2}$

$x^2 + xy - y^2$

$x - y$

$x^3 + x^2y - xy^2$

$- x^2y - xy^2 + y^3$

$\underline{x^3 - 2xy^2 + y^3}$

$x + y$

$x - y$

$x^2 + xy$

$- xy - y^2$

$\underline{x^2 - y^2}$

$x^2 + y$

$x^2 + y$

$x^4 + yx^2$

$+ yx^2 + y^2$

$\underline{x^4 + 2yx^2 + y^2}$

$x^2 + xy + y^2$

$x - y$

$x^3 + x^2y + xy^2$

$- xy - xy^2 - y^3$

$\underline{x^3 * * - y^3}$

*Note.*

*Note.* In the multiplication of compound quantities, it is the best way to set them down in order, according to the powers and the letters of the alphabet. And in multiplying them, begin at the left-hand side, and multiply from the left hand towards the right, in the manner that we write, which is contrary to the way of multiplying numbers. But in setting down the several products, as they arise, in the second and following lines, range them under the like terms in the lines above, when there are such like quantities; which is the easiest way for adding them up together.

In many cases, the multiplication of compound quantities is only to be performed by setting them down one after another, each within or under a vinculum, with a sign of multiplication between them. As  $(a+b) \times (a-b) \times 3ab$ , or  $\underline{a+b} \cdot \underline{a-b} : 3ab$ .

#### EXAMPLES FOR PRACTICE.

1. Multiply  $12ax$  by  $3a$ . Ans.  $36a^2x$ .
  2. Multiply  $4x^2 - 2y$  by  $2y$ . Ans.  $8x^2y - 4y^2$ .
  3. Multiply  $2x + 4y$  by  $2x - 4y$ . Ans.  $4x^2 - 16y^2$ .
  4. Multiply  $x^2 - xy + y^2$  by  $x + y$ . Ans.  $x^3 + y^3$ .
  5. Multiply  $x^3 + x^2y + xy^2 + y^3$  by  $x - y$ . Ans.  $x^4 - y^4$ .
  6. Multiply  $x^2 + xy + y^2$  by  $x^2 - xy + y^2$ .
  7. Multiply  $3x^2 - 2xy + 5$  by  $x^2 + 2xy - 3$ .
  8. Multiply  $2a^2 - 3ax + 4x^2$  by  $5a^2 - 6ax - 2x^2$ .
  9. Multiply  $3x^3 + 2x^2y^2 + 3y^3$  by  $2x^3 - 3x^2y^2 + 5y^3$ .
  10. Multiply  $a^2 + ab + b^2$  by  $a - b$ .
- 

#### DIVISION.

DIVISION in Algebra, like that in numbers, is the converse of multiplication; and it is performed like that of numbers also, by beginning at the left-hand side, and dividing all the parts of the dividend by the divisor, when they can be so divided; or else by setting them down like a fraction, the dividend over the divisor, and then abbreviating the fraction as much as can be done. This will naturally divide into the following particular cases.

## CASE I.

*When the Divisor and Dividend are both Simple Quantities;*

SET the terms both down as in division of numbers, either the divisor before the dividend, or below it, like the denominator of a fraction. Then abbreviate these terms as much as can be done, by cancelling or striking out all the letters that are common to both of them, and also dividing the one co-efficient by the other, or abbreviating them after the manner of a fraction, by dividing them by their common measure.

*Note.* Like signs in the two factors make + in the quotient; and unlike signs make - ; the same as in multiplication\*.

## EXAMPLES.

1. To divide  $8ab$  by  $2a$ .

$$\text{Here } 8ab \div 2a, \text{ or } 2a ) 8ab, \text{ or } \frac{8ab}{2a} = 4b.$$

2. Also  $a \div a = \frac{a}{a} = 1$ ; and  $abc \div bcd = \frac{abc}{bcd} = \frac{a}{d}$ .

3. Divide  $16x^2$  by  $8x$ . Ans.  $2x$ .

4. Divide  $12a^2x^2$  by  $-3a^2x$ . Ans.  $-4x$ .

5. Divide  $-15ay^2$  by  $3ay$ . Ans.  $-5y$ .

6. Divide  $-18ax^2y$  by  $-8axz$ . Ans.  $\frac{9xy}{4z}$ .

\* Because the divisor multiplied by the quotient, must produce the dividend. Therefore,

1. When both the terms are +, the quotient must be +; because + in the divisor  $\times$  + in the quotient, produces + in the dividend.

2. When the terms are both -, the quotient is also +; because - in the divisor  $\times$  + in the quotient, produces - in the dividend.

3. When one term is + and the other -, the quotient must be -; because + in the divisor  $\times$  - in the quotient produces - in the dividend, or - in the divisor  $\times$  + in the quotient gives - in the dividend.

So that the rule is general; like signs give +, and unlike signs give -, in the quotient.

## CASE II.

*When the Dividend is a Compound Quantity, and the Divisor a Simple one;*

**DIVIDE** every term of the dividend by the divisor, as in the former case.

## EXAMPLES.

$$1. (ab + b^2) \div 2b, \text{ or } \frac{ab + b^2}{2b} = \frac{a + b}{2} = \frac{1}{2}a + \frac{1}{2}b.$$

$$2. (10ab + 15ax) \div 5a, \text{ or } \frac{10ab + 15ax}{5a} = 2b + 3x.$$

$$3. (30az - 48z) \div z, \text{ or } \frac{30az - 48z}{z} = 30a - 48.$$

$$4. \text{ Divide } 4ab - 8ax + a \text{ by } 2a.$$

$$5. \text{ Divide } 3x^2 - 15 + 6x + 3a \text{ by } 3x.$$

$$6. \text{ Divide } 3abc + 12abx - 9ab \text{ by } 3ab.$$

$$7. \text{ Divide } 10a^2x - 15x^2 - 5x \text{ by } 5x.$$

$$8. \text{ Divide } 15a^2bc - 12acx^2 + 5ad^2 \text{ by } - 5ac.$$

$$9. \text{ Divide } 12a + 3ay - 18y \text{ by } 21a.$$

$$10. \text{ Divide } - 40a^2b^2 + 60ab \text{ by } - 6ab.$$

## CASE III.

*When the Divisor and Dividend are both Compound Quantities;*

1. SET them down as in common division of numbers, the divisor before the dividend, with a small crooked line between them, and ranging the terms according to the powers of some one of the letters in both, the higher powers of it before the lower.

2. Divide the first term of the dividend by the first term of the divisor, as in the first case, and place the result in the quotient.

3. Multiply the whole divisor by the term thus found, and subtract the result from the dividend.

4. To this remainder bring down as many terms of the dividend as are requisite for the next operation, dividing as before; and so on to the end, as in common arithmetic.

*Note.*

*Note.* If the divisor be not exactly contained in the dividend, the quantity which remains after the operation is finished, may be placed over the divisor, like a vulgar fraction, and set down at the end of the quotient, as in common arithmetic.

## EXAMPLES.

$$\begin{array}{r} x + y ) \ x^2 + 2xy + y^2 ( x + y \\ \underline{x^2 + xy} \\ \underline{xy + y^2} \end{array}$$

$$\begin{array}{r} x + x ) \ a^3 + 5a^2x + 5ax^2 + x^3 ( a^2 + 4ax + x^2 \\ \underline{a^3 + a^2x} \\ \underline{4a^2x + 5ax^2} \\ \underline{4ax + 4ax^2} \\ \underline{ax^2 + x^3} \end{array}$$

$$\begin{array}{r} x - 3 ) \ x^3 - 9x^2 + 27x - 27 ( x^2 - 6x + 9 \\ \underline{x^3 - 3x^2} \\ \underline{- 6x^2 + 27x} \\ \underline{- 6x^2 + 18x} \\ \underline{9x - 27} \end{array}$$

$$\begin{array}{r} x - x ) \ a^3 - x^3 ( a^2 + ax + x^2 \\ \underline{a^3 - a^2x} \\ \underline{a^2x - x^3} \\ \underline{a^2x - ax^2} \\ \underline{ax^2 - x^3} \\ \underline{ax^2 - x^3} \end{array}$$

$$\begin{array}{r}
 b - y ) b^4 - 3y^4 ( b^3 + b^2y + by^2 + y^3 - \frac{2y^4}{b - y} \\
 b^4 - b^3y \\
 \hline
 b^3y - 3y^4 \\
 b^2y - b^2y^2 \\
 \hline
 b^2y^2 - 3y^4 \\
 b^2y^2 - by^3 \\
 \hline
 by^3 - 3y^4 \\
 by^3 - y^4 \\
 \hline
 - 2y^4
 \end{array}$$

## EXAMPLES FOR PRACTICE.

1. Divide  $a^2 + 2ax + x^2$  by  $a + x$ . Anf.  $a + x$ .
2. Divide  $a^3 - 3a^2y + 3ay^2 - y^3$  by  $a - y$ . Anf.  $a^2 - 2ay + y^2$ .
3. Divide 1 by  $1 - x$ . Anf.  $1 + x + x^2 + x^3 + \&c.$
4. Divide  $6x^4 - 96$  by  $3x - 6$ . Anf.  $2x^3 + 4x^2 + 8x + 16$ .
5. Divide  $a^5 - 5a^4x + 10a^3x^2 - 10a^2x^3 + 5ax^4 - x^5$  by  $a^2 - 2ax + x^2$ . Anf.  $a^3 - 3a^2x + 3ax^2 - x^3$ .
6. Divide  $48x^3 - 76ax^2 - 64a^2x + 105a^3$  by  $2x - 3a$ .
7. Divide  $y^6 - 3y^4x^2 + 3y^2x^4 - x^6$  by  $y^3 - 3y^2x + 3yx^2 - x^3$ .
8. Divide  $a^5 - x^5$  by  $a - x$ .
9. Divide  $a^3 + 5a^2x + 5ax^2 + x^3$  by  $a + x$ .
10. Divide  $a^4 + 4a^2b^2 - 32b^4$  by  $a + 2b$ .
11. Divide  $24a^4 - b^4$  by  $3a - 2b$ .

## ALGEBRAIC FRACTIONS.

ALGEBRAIC FRACTIONS have the same names and rules of operation, as numeral fractions in common arithmetic; as appears in the following Problems:

## PROBLEM I.

*To Reduce a Mixed Quantity to an Improper Fraction.*

MULTIPLY the integer by the denominator of the fraction, and to the product add the numerator; then the denominator being placed under this sum, will give the improper fraction required.

## EXAMPLES.

1. Reduce  $3\frac{5}{7}$ , and  $a - \frac{b}{c}$  to improper fractions.

$$\text{First, } 3\frac{5}{7} = \frac{3 \times 7 + 5}{7} = \frac{21 + 5}{7} = \frac{26}{7} \text{ the Ans.}$$

$$\text{And, } a - \frac{b}{c} = \frac{a \times c - b}{c} = \frac{ac - b}{c} \text{ the Ans.}$$

2. Reduce  $x + \frac{x^2}{a}$  and  $x - \frac{a^2 - x^2}{x}$  to improper fractions.

$$\text{First, } x + \frac{x^2}{a} = \frac{x \times a + x^2}{a} = \frac{ax + x^2}{a} \text{ the Ans.}$$

$$\text{And, } x - \frac{a^2 - x^2}{x} = \frac{x^2 - a^2 + x^2}{x} = \frac{2x^2 - a^2}{x} \text{ Ans.}$$

3. Reduce  $8\frac{6}{7}$  to an improper fraction. Ans.  $\frac{62}{7}$ .

4. Reduce  $1 - \frac{2x}{a}$  to an improper fraction. Ans.  $\frac{a - 2x}{a}$ .

5. Reduce  $x - \frac{ax + x^2}{2a}$  to an improper fraction.

6. Reduce  $10 + \frac{2x - 8}{3x}$  to an improper fraction.

7. Reduce  $a + \frac{1 - x - b}{b}$  to an improper fraction.

8. Reduce  $1 + 2x - \frac{x - 3}{5x}$  to an improper fraction.

## PROBLEM II.

*To Reduce an Improper Fraction to a Whole or Mixed Quantity.*

DIVIDE the numerator by the denominator, for the integral part; and place the remainder, if any, over the denominator, for the fractional part; the two joined together will be the mixed quantity required.

## EXAMPLES.

1. To reduce  $\frac{17}{5}$ , and  $\frac{ax + a^2}{x}$  to mixed quantities.

First,  $\frac{17}{5} = 17 \div 5 = 3\frac{2}{5}$ , the Answer required.

$$\text{And } \frac{ax + a^2}{x} = \frac{ax + a^2}{x} \div x = a + \frac{a^2}{x} \text{ Ans.}$$

2. To reduce  $\frac{ab - a^2}{b}$ , and  $\frac{ay + 2y^2}{a+y}$  to mixed quantities.

$$\text{First, } \frac{ab - a^2}{b} = \frac{ab - a^2}{b} \div b = a - \frac{a^2}{b} \text{ Ans.}$$

$$\text{And, } \frac{ay + 2y^2}{a+y} = \frac{ay + 2y^2}{a+y} \div \frac{a+y}{a+y} = y + \frac{y^2}{a+y}.$$

3. Let  $\frac{35}{8}$  and  $\frac{3ab - b^2}{a}$  be reduced to whole or mixed quantities

$$\text{Ans. } 4\frac{3}{8}, \text{ and } 3b - \frac{b^2}{a}.$$

4. Let  $\frac{2x^2y}{2x}$  and  $\frac{a^2 + x^2}{a - x}$  be reduced to whole or mixed quantities.

5. Let  $\frac{x^2 - y^2}{x + y}$ , and  $\frac{x^3 - y^3}{x - y}$  be reduced to whole or mixed quantities.

6. Reduce  $\frac{10x^2 - x + 3}{5x}$  to a mixed quantity.

7. Reduce  $\frac{12x^3 + 3x^2}{4x^3 + x^2 - 4x - 1}$  to a mixed quantity.

## PROBLEM III.

*To Reduce Fractions to a Common Denominator.*

MULTIPLY every numerator, separately, into all the denominators except its own, for the new numerators; and all the denominators together, for the common denominator\*.

\* When the denominators have a common divisor, it will be better, instead of multiplying by the whole denominators, to multiply only by those parts which arise from dividing by the common divisor.

## EXAMPLES.

1. Reduce  $\frac{a}{b}$  and  $\frac{b}{c}$  to a common denominator.

$$\left. \begin{array}{l} a \times c = ac \\ b \times b = b^2 \end{array} \right\} \text{the new numerators.}$$

$$\underline{b \times c = bc} \text{ the common denominator.}$$

therefore  $\frac{a}{b}$  and  $\frac{b}{c} = \frac{ac}{bc}$  and  $\frac{b^2}{bc}$  the fractions required.

2. Reduce  $\frac{a}{b}$ ,  $\frac{b}{c}$ , and  $\frac{c}{d}$  to a common denominator.

$$\left. \begin{array}{l} a \times c \times d = acd \\ b \times b \times d = b^2 d \\ c \times b \times c = c^2 b \end{array} \right\} \text{the numerators.}$$

$$\underline{b \times c \times d = bcd} \text{ the com. denom.}$$

therefore  $\frac{a}{b}$ ,  $\frac{b}{c}$ , and  $\frac{c}{d} = \frac{acd}{bcd}$ ,  $\frac{b^2 d}{bcd}$ , and  $\frac{bc^2}{bcd}$ , the frac. required.

3. Reduce  $\frac{2x}{a}$  and  $\frac{b}{c}$  to equivalent fractions, having a common denominator.

$$\text{Ans. } \frac{2cx}{ac} \text{ and } \frac{ab}{ac}.$$

4. Reduce  $\frac{a}{b}$  and  $\frac{a+b}{c}$  to fractions having a common denominator.

$$\text{Ans. } \frac{ac}{bc} \text{ and } \frac{ab+b^2}{bc}.$$

5. Reduce  $\frac{3x}{2a}$ ,  $\frac{2b}{3c}$ , and  $d$ , to fractions having a common denominator.

$$\text{Ans. } \frac{9cx}{6ac}, \frac{4ab}{6ac}, \text{ and } \frac{6acd}{6ac}.$$

6. Reduce  $\frac{3}{4}$ ,  $\frac{2x}{3}$  and  $a + \frac{2x}{a}$ , to fractions having a common denominator.

$$\text{Ans. } \frac{9a}{12a}, \frac{8ax}{12a}, \text{ and } \frac{12a^2 + 24x}{12a}.$$

7. Reduce  $\frac{1}{2}$ ,  $\frac{x^2}{3}$  and  $\frac{a^2 + x^2}{a+x}$  to a common denominator.

8. Reduce  $\frac{a}{2}$ ,  $\frac{2}{3}$  and  $\frac{d}{a}$  to a common denominator.

## PROBLEM IV.

*To find the Greatest Common Measure of the Terms of a Fraction.*

1. RANGE the quantities according to the dimensions of some letters, as is shewn in division.

2. Divide the greater term by the less, and the last divisor by the last remainder, and so on till nothing remains; then the divisor last used will be the common measure required.

*Note.* All the letters or figures which are common to each term of the divisors, must be thrown out of them, before they are used in the operation\*.

## EXAMPLES.

1. To find the greatest common measure of  $\frac{cx + x^2}{ca^2 + a^2x}$ .

$$\begin{array}{r} cx + x^2 ) ca^2 + a^2x \\ \text{or } c + x ) ca^2 + a^2x \quad (a^2 \\ \hline ca^2 + a^2x \end{array}$$

Therefore the greatest common measure is  $c + x$ .

2. To find the greatest common measure of  $\frac{x^3 - b^2x}{x^2 + 2bx + b^2}$

$$\begin{array}{r} x^3 - b^2x \quad (x \\ x^3 + 2bx^2 + b^2 \quad \hline \\ - 2bx^2 - 2b^2x ) x^2 + 2bx + b^2 \\ \text{or } x + b \quad ) x^2 + 2bx + b^2 \quad (x + b. \\ \hline x^2 + bx \\ \hline bx + b^2 \\ bx + b^2 \end{array}$$

Therefore  $x + b$  is the greatest common divisor.

3. To find the greatest common divisor of  $\frac{x^2 - 1}{xy + y}$ .

Ansf.  $x + 1$ .

\* The simple divisors, in this rule, may be easily found, by inspection.

4. To find the greatest common divisor of  $\frac{x^4 - b^4}{x^5 + b^2x^3}$ .  
 Ans.  $x^2 + b^2$ .

5. To find the greatest common measure of

$$\frac{5a^5 + 10a^3b + 5a^3b^2}{a^3b + 2a^2b^2 + 2ab^3 + b^4}$$

## PROBLEM V.

*To Reduce a Fraction to its Lowest Terms.*

1. FIND the greatest common measure, as in the last problem.

2. Divide both the terms of the fraction by the common measure thus found, and it will reduce it to its lowest terms, as was required.

3. Or divide the terms by any quantity which it may appear will divide them both.

## EXAMPLES.

1. Reduce  $\frac{cx + x^2}{ca^2 + a^2x}$  to its lowest terms.  
 or  $c + x$ )  $\frac{cx + x^2}{ca^2 + a^2x} (a^2$   
 $\underline{ca^2 + a^2x}$

Here  $cx + x^2$  is divided by  $x$  which is common to both terms.

Therefore  $c + x$  is the greatest common measure,  
 and  $c + x$ )  $\frac{cx + x^2}{ca^2 + a^2x} = \frac{x}{a^2}$ , is the fraction required.

3. Having  $\frac{x^3 - b^2x}{x^2 + 2bx + b^2}$  given, it is required to reduce it to its least terms.

$$\begin{aligned} & x^2 + 2bx + b^2) \frac{x^3 - b^2x}{x^2 + 2bx + b^2} (x \\ & \quad \underline{- 2bx^2 - 2b^2x}) \frac{x^2 + 2bx + b^2}{x^2 + bx} \\ & \quad \text{or } x + b) \frac{x^2 + 2bx + b^2}{x^2 + bx} (x + b \\ & \quad \underline{- bx^2 - bx}) \frac{bx + b^2}{bx + b^2} \\ & \quad \underline{bx + b^2} \end{aligned}$$

Therefore

Therefore  $x + b$  is the greatest common measure, and  $x + b) \frac{x^2 - b^2x}{x^2 + 2bx + b^2} = \frac{x^2 - bx}{x + b}$  is the fraction required.

3. Reduce  $\frac{x^4 - b^4}{x^3 - b^2x^2}$  to its lowest terms. Ans.  $\frac{x^2 + b^2}{x^3}$ .

4. Reduce  $\frac{x^2 - y^2}{x^4 - y^4}$  to its lowest terms. Ans.  $\frac{1}{x^2 + y^2}$ .

5. Reduce  $\frac{a^4 - x^4}{a^2 - a^2x - ax^2 + x^3}$  to its lowest terms.

6. Reduce  $\frac{5a^5 + 10a^4x + 5a^3x^2}{a^3x + 2a^2x^2 + 2ax^3 + x^4}$  to its lowest terms.

7. Reduce  $\frac{a^3 - ab^2}{a^2 + 2ab + b^2}$  to its lowest terms.

### PROBLEM VI.

*To Add Fractional Quantities together.*

1. If the fractions have a common denominator, add all the numerators together, then under their sum write the common denominator, and it will give the sum of the fractions required.

2. If they have not a common denominator, reduce them to a common denominator, and then add them as before.

### EXAMPLES.

1. Having  $\frac{x}{2}$  and  $\frac{x}{3}$  given, to find their sum.

Here  $\frac{x \times 3}{x \times 2} = \frac{3x}{2x}$  } the numerators.  
 $\underline{\underline{}}$

and  $2 \times 3 = 6$  the com. denom.

theref.  $\frac{3x}{6} + \frac{2x}{6} = \frac{5x}{6}$  is the sum required.

2. Having  $\frac{a}{b}$ ,  $\frac{c}{a}$ , and  $\frac{e}{f}$  given, to find their sum.

Here  $\frac{a \times d \times f}{b \times c \times f} = \frac{adf}{bcf}$  } the numerators.  
 $\frac{c \times b \times f}{b \times c \times f} = \frac{cbf}{bcf}$   
 $\frac{e \times b \times d}{b \times c \times f} = \frac{ebd}{bcf}$  }  
 $\underline{\underline{}}$

and  $b \times d \times f = bdf$  the com. denom.

theref.  $\frac{adf}{bdf} + \frac{cbf}{bdf} + \frac{ebd}{bdf} = \frac{adf + cbf + ebd}{bdf}$

the sum required.

\*3. Let  $a - \frac{3x^2}{b}$  and  $b + \frac{2ax}{c}$  be added together.

$$\left. \begin{array}{l} 3x^2 \times c = 3cx^2 \\ 2ax \times b = 2abx \end{array} \right\} \text{the numerators.}$$

and  $b \times c = bc$  the common denominator.

$$\text{Therefore } a - \frac{3x^2}{b} + b + \frac{2ax}{c} = a - \frac{3cx^2}{bc} + b + \frac{2abx}{bc}$$

$$= a + b + \frac{2abx - 3cx^2}{bc} \text{ the sum required.}$$

4. Add  $\frac{3x}{2b}$  and  $\frac{x}{5}$  together. Anf.  $\frac{15x + 2bx}{10b}$ .

5. Add  $\frac{x}{2}$ ,  $\frac{x}{3}$  and  $\frac{x}{4}$  together. Anf.  $\frac{13}{12}x$  or  $x + \frac{x}{12}$ .

6. Add  $\frac{x-2}{3}$  and  $\frac{4x}{7}$  together. Anf.  $\frac{19x - 14}{21}$ .

7. Add  $x + \frac{x-2}{3}$  to  $3x + \frac{2x-3}{4}$ . Anf.  $4x + \frac{10x - 17}{12}$ .

8. It is required to add  $4x$ ,  $\frac{5x^2}{2a}$  and  $\frac{a+x}{2x}$  together.

9. It is required to add  $\frac{2x}{3}$ ,  $\frac{7x}{4}$  and  $\frac{2x+1}{5}$  together.

10. It is required to add  $4x$ ,  $\frac{7x}{9}$  and  $2 + \frac{x}{5}$  together.

11. It is required to add  $3x + \frac{2x}{5}$  and  $x - \frac{8x}{9}$  together.

### PROBLEM VII.

*To Subtract one Fractional Quantity from another.*

1. REDUCE the fractions to a common denominator, as in addition, if they have not a common denominator.

2. Subtract the numerators from each other, and under their difference write the common denominator, and it will give the difference of the fractions required †.

\* In the addition of mixed quantities, it is best to bring the fractional parts only to a common denominator, and to affix their sum to the sum of the integers, interposing the proper sign.

† The same rule may be observed for mixed quantities, in subtraction, as in addition.

## EXAMPLES.

1. To find the difference of  $\frac{x}{3}$  and  $\frac{2x}{11}$ .

Here  $x \times 11 = 11x$  } the numerators.  
 $2x \times 3 = 6x$  }

and  $3 \times 11 = 33$  the common denominator.

theref.  $\frac{11x}{33} - \frac{6x}{33} = \frac{5x}{33}$  is the difference required.

2. To find the difference of  $\frac{x-a}{3b}$  and  $\frac{2a-4x}{5c}$ .

Here  $x-a \times 5c = 5cx - 5ac$  } the nu-  
 $2a-4x \times 3b = 6ab - 12bx$  } merators.

and  $3b \times 5c = 15bc$  the com. denom.

Then  $\frac{5cx-5ac}{15bc} - \frac{6ab-12bx}{15bc} = \frac{5cx-5ac-6ab+12bx}{15bc}$   
is the difference required.

3. Required the difference of  $\frac{12x}{7}$  and  $\frac{3x}{5}$ .

4. Required the difference of  $5y$  and  $\frac{3y}{8}$ .

5. Required the difference of  $\frac{3x}{7}$  and  $\frac{2x}{9}$ .

6. Subtract  $\frac{c}{d}$  from  $\frac{a+x}{b}$ .

7. Take  $\frac{2x+7}{3}$  from  $\frac{3x+a}{5b}$ .

8. Take  $x - \frac{x-a}{c}$  from  $3x + \frac{x}{b}$ .

## PROBLEM VIII.

*To Multiply Fractional Quantities together.*

MULTIPLY the numerators together, for a new numerator, and the denominators for a new denominator; and it will give the product required \*.

## EXAMPLES.

\* 1. When the numerator of one fraction, and the denominator of the other, can be divided by some quantity, which is common to both, the quotients may be used instead of them.

2. When a fraction is to be multiplied by an integer, the product is found by multiplying the numerator by it; and if the integer be the

## EXAMPLES.

1. Required to find the product of  $\frac{x}{6}$  and  $\frac{2x}{9}$ .

Here  $\frac{x \times 2x}{6 \times 9} = \frac{2x^2}{54} = \frac{x^2}{27}$  the product required.

2. Required the product of  $\frac{x}{2}$ ,  $\frac{4x}{5}$ , and  $\frac{10x}{21}$ .

$\frac{x \times 4x \times 10x}{2 \times 5 \times 21} = \frac{40x^3}{210} = \frac{4x^3}{21}$  the product required.

3. Required the product of  $\frac{x}{a}$  and  $\frac{a+x}{a+c}$ .

Here  $\frac{x \times (a+x)}{a \times (a+c)} = \frac{ax + x^2}{a^2 + ac}$  the product required.

4. Required the product of  $\frac{3x}{2}$  and  $\frac{3a}{b}$ .

5. Required the product of  $\frac{2x}{5}$  and  $\frac{3x^2}{2a}$ .

6. To multiply  $\frac{2x}{a}$ , and  $\frac{3ab}{c}$ , and  $\frac{3ac}{2b}$  together.

7. Required the product of  $b + \frac{bx}{a}$  and  $\frac{a}{x}$ .

8. Required the product of  $\frac{x^2 - b^2}{bc}$  and  $\frac{x^2 + b^2}{b + c}$ .

9. Required the product of  $x$ , and  $\frac{x+1}{a}$ , and  $\frac{x-1}{a+b}$ .

10. Multiply  $a + \frac{x}{2a} - \frac{x^2}{4a^2}$  by  $x - \frac{a}{2x} + \frac{a^2}{4x^2}$ .

## PROBLEM IX.

*To Divide one Fractional Quantity by another.*

MULTIPLY the denominator of the divisor by the numerator of the dividend, for a new numerator, and the numerator of the divisor by the denominator of the dividend, for a new denominator \*.

Or,

---

the same with the denominator, the numerator may be taken for the product.

3. When a fraction is to be multiplied by any quantity, it is the same thing whether the numerator be multiplied by it, or the denominator divided by it.

\* 1. If the fractions to be divided have a common denominator, take the numerator of the dividend for a new numerator, and the numerator of the divisor for the denominator.

2. When

Or, invert the terms of the divisor, and then multiply by it exactly as in multiplication.

## EXAMPLES.

1. Required the quotient of  $\frac{x}{3}$  divided by  $\frac{2x}{9}$ .

Here  $\frac{x}{3} \times \frac{9}{2x} = \frac{9x}{6x} = \frac{3}{2} = 1\frac{1}{2}$  is the quot. required.

2. Required the quotient of  $\frac{2a}{b}$  divided by  $\frac{4c}{d}$ .

Here  $\frac{2a}{b} \times \frac{d}{4c} = \frac{2ad}{4bc} = \frac{ad}{2bc}$  is the quotient required.

3. Find the quotient of  $\frac{x+a}{2x-2b}$  divided by  $\frac{x+b}{5x+a}$ .

$\frac{x+a}{2x-2b} \times \frac{5x+a}{x+b} = \frac{5x^2 + 6ax + a^2}{2x^2 - 2b^2}$  the quot. required.

4. Find the quotient of  $\frac{2x^3}{a^3+x}$  divided by  $\frac{x}{x+a}$ .

$\frac{2x^2}{a^3+x^3} \times \frac{x+a}{x} = \frac{2x^2 \times (x+a)}{(a^3+x^3) \times x} = \frac{2x}{x^2 - ax + a^2}$  is the quotient required.

5. Let  $\frac{7x}{5}$  be divided by  $\frac{12}{13}$ :

6. Let  $\frac{4x^2}{7}$  be divided by  $5x$ .

7. Let  $\frac{x+1}{6}$  be divided by  $\frac{2x}{3}$ .

8. Let  $\frac{x}{x-1}$  be divided by  $\frac{x}{2}$ .

9. Let  $\frac{5x}{3}$  be divided by  $\frac{2a}{3b}$ .

10. Let  $\frac{x-b}{8cd}$  be divided by  $\frac{3cx}{4d}$ .

11. Divide  $\frac{x^4 - b^4}{x^4 - 2bx + b^2}$  by  $\frac{x^2 + bx}{x-b}$ .

2. When a fraction is to be divided by any quantity, it is the same thing whether the numerator be divided by it, or the denominator multiplied by it.

3. When the two numerators, or the two denominators, can be divided by some common quantity, that quantity may be thrown out of each, and the quotients used instead of the fractions first proposed.

## INVOLUTION.

INVOLUTION is the raising of powers from any proposed root; or the method of finding the square, cube, biquadrate, &c, of any given quantity.

\* MULTIPLY the quantity into itself as many times as there are units in the index less one, and the last product will be the power required. Or,

Multiply the index of the quantity by the index of the power, and the result will be the same as before.

*Note.* When the sign of the root is +, all the powers of it will be +; and when the sign is -, all the even powers will be +, and all the odd powers -, as is evident from multiplication.

## EXAMPLES.

$a$ , the root

$a^2$  = square

$a^3$  = cube

$a^4$  = 4th power

$a^5$  = 5th power

&c.

- 3 $a$ , the root

+ 9 $a^2$  = square

- 27 $a^3$  = cube

+ 81 $a^4$  = 4th power

- 243 $a^5$  = 5th power

-  $\frac{2ax^2}{3b}$ , the root

+  $\frac{4a^2x^4}{9b^2}$  = square

-  $\frac{8a^3x^6}{27b^3}$  = cube

+  $\frac{16a^4x^8}{81b^4}$  = 4th power.

$a^2$ , the root

$a^4$  = square

$a^6$  = cube

$a^8$  = 4th power

$a^{10}$  = 5th power

&c.

- 2 $ax^2$ , the root

+ 4 $ax^4$  = square

- 8 $a^3x^6$  = cube

+ 16 $a^4x^8$  = 4th power

- 32 $a^5x^{10}$  = 5th power.

$x$ , the root

$x^2$  = square.

$x^3$  = cube

$x^4$  = biquadrate

\* Any power of the product of two or more quantities is equal to the same power of each of the factors, multiplied together.

And any power of a fraction is equal to the same power of the numerator, divided by the like power of the denominator.

Also, powers or roots of the same quantity, are multiplied by one another, by adding their exponents; or divided, by subtracting their exponents.

Thus,  $a^3 \times a^2 = a^{3+2} = a^5$ . And  $a^3 \div a^2$  or  $\frac{a^3}{a^2} = a^{3-2} = a$ .

$x = a$ .

$$\begin{array}{ll}
 x - a = \text{root} & x + a = \text{root} \\
 x - a & x + a \\
 \hline
 x^2 - ax & x^2 + ax \\
 - ax + a^2 & + ax + a^2 \\
 \hline
 x^2 - 2ax + a^2 \text{ square} & x^2 + 2ax + a^2 \\
 x - a & x + a \\
 \hline
 x^3 - 2ax^2 + a^2x & x^3 + 2ax^2 + a^2x \\
 - ax^2 + 2a^2x - a^3 & + ax^2 + 2a^2x + a^3 \\
 \hline
 x^3 - 3ax^2 + 3a^2x - a^3 & x^3 + 3ax^2 + 3a^2x + a^3
 \end{array}$$

the cubes, or third powers, of  $x + a$  and  $x - a$ .

#### EXAMPLES FOR PRACTICE.

1. Required the cube or 3d power of  $2a^2$ .
2. Required the 4th power of  $2a^2x$ .
3. Required the 3d power of  $-8x^2y^3$ .
4. To find the biquadrate of  $-\frac{2a^2x}{3b^2}$ .
5. To find the 6th power of  $a^{\frac{1}{2}}$ .
6. Required the 5th power of  $a - x$ .

Sir ISAAC NEWTON's RULE for raising a Binomial or Residual Quantity to any Power whatever\*.

1. *To find the Terms without the Co-efficients.* The index of the first, or leading quantity, begins with that of the given power, and decreases continually by 1, in every term to the last; and in the following quantity, the indices of the terms are 0, 1, 2, 3, 4, &c.

\* This rule, expressed in general terms, is as follows:

$$\underline{a+b^n} = a^n + n \cdot a^{n-1}b + n \cdot \frac{n-1}{2} a^{n-2}b^2 + n \cdot \frac{n-1}{2} \cdot \frac{n-2}{3} a^{n-3}b^3 \&c.$$

$$\underline{a-b^n} = a^n - n \cdot a^{n-1}b + n \cdot \frac{n-1}{2} a^{n-2}b^2 - n \cdot \frac{n-1}{2} \cdot \frac{n-2}{3} a^{n-3}b^3 \&c.$$

*Note.* The sum of the co-efficients, in every power, is equal to the number 2, raised to that power. Thus  $1 + 1 = 2$  for the first power;  $1 + 2 + 1 = 4 = 2^2$  for the square;  $1 + 3 + 3 + 1 = 8 = 2^3$  for the cube, or third power; and so on.

2. To find the Co-efficients. The first is always 1, and the second is the index of the power; and in general, if the co-efficient of any term be multiplied by the index of the leading quantity in that term, and the product be divided by the number of terms to that place, it will give the co-efficient of the term next following; which rule will find all the co-efficients, one after another.

*Note.* The whole number of terms will be one more than the index of the given power; and when both terms of the root are +, all the terms of the power will be +; but if the second term be -, all the odd terms will be +, and all the even terms -, which causes the terms to be + and - alternately.

## EXAMPLES.

1. Let  $a + x$  be involved to the 5th power.

The terms without the co-efficients will be

$$a^5, a^4x, a^3x^2, a^2x^3, ax^4, x^5,$$

and the co-efficients will be

$$1, 5, \frac{5 \times 4}{2}, \frac{10 \times 3}{3}, \frac{10 \times 2}{4}, \frac{5 \times 1}{5};$$

$$\text{or, } 1, 5, 10, 10, 5, 1;$$

And therefore the 5th power altogether is

$$a^5 + 5a^4x + 10a^3x^2 + 10a^2x^3 + 5ax^4 + x^5.$$

But it is best to set down only the co-efficients and the powers of the letters at once, in one line, without the intermediate lines in the above example, as in the example here below.

2. Let  $x - a$  be involved to the 6th power.

The terms with the co-efficients will be

$$x^6 - 6x^5a + 15x^4a^2 - 20x^3a^3 + 15x^2a^4 - 6xa^5 + a^6.$$

3. Required the 4th power of  $x - a$ .

$$\text{Ans. } x^4 - 4x^3a + 6x^2a^2 - 4xa^3 + a^4.$$

4. Required the 7th power of  $x + a$ .

$$\text{Ans. } x^7 + 7x^6a + 21x^5a^2 + 35x^4a^3 + 35x^3a^4 + 21x^2a^5 + 7xa^6 + a^7.$$

And thus any other powers may be set down at once, in the same manner.

# ALGEBRA.

## EVOLUTION.

**EVOLUTION** is the reverse of Involution, being the method of finding the square root, cube root, &c, of any given quantity, whether simple or compound.

### CASE I.

*To find the Roots of Simple Quantities.*

**EXTRACT** the root of the co-efficient, for the numeral part; and divide the index of the letter or letters, by the index of the power, and it will give the root of the literal part; then annex this to the former, for the whole root sought\*.

### EXAMPLES.

1. Required the square root of  $9x^2$ ; and the cube root of  $3x^3$ .

$$\text{Ans: } \sqrt{9x^2} = 3x^{\frac{2}{2}} = 3x. \text{ And } \sqrt[3]{8x^3} = 2x^{\frac{3}{3}} = 2x.$$

2. To find the sq. root of  $\frac{3x^2y^2}{4a^2}$ , and cube root of  $\frac{16x^4y^3}{27a^3}$ .

$$\text{Ans: } \sqrt{\frac{3x^2y^2}{4a^2}} = \frac{xy}{2a} \sqrt{3}. \text{ And } \sqrt[3]{\frac{16x^4y^3}{27a^3}} = \frac{2xy}{3a} \sqrt[3]{2x}.$$

\* Any even root of an affirmative quantity, may be either + or - : thus the square root of  $+a^2$  is either  $+a$ , or  $-a$ ; for  $+a \times +a = +a^2$ , and  $-a \times -a = +a^2$  also.

And an odd root of any quantity will have the same sign as the quantity itself: thus the cube root of  $+a^3$  is  $+a$ , and the cube root of  $-a^3$  is  $-a$ ; for  $+a \times +a \times +a = +a^3$ , and  $-a \times -a \times -a = -a^3$ .

Any even root of a negative quantity is impossible; for neither  $+a \times +a$ , nor  $-a \times -a$  can produce  $-a^2$ .

Any root of a product is equal to the like root of each of the factors multiplied together.

And any root of a fraction, is equal to the like root of the numerator, divided by the same root of the denominator.

3. Required

3. Required the square root of  $3a^2x^6$ . Anf.  $ax^3\sqrt{3}$ .  
 4. Required the cube root of  $-125a^3x^6$ . Anf.  $-5ax^2$ .  
 5. Required the square root of  $\frac{9x^2y^2}{4a^3}$ . Anf.  $\frac{3xy}{2a\sqrt{a}}$ .  
 6. Required the 4th root of  $256a^4x^8$ . Anf.  $4ax^2$ .  
 7. To find the 5th root of  $-32x^5y^{10}$ . Anf.  $-2xy^2$ .

## CASE II.

*To find the Square Root of a Compound Quantity.*

THIS is performed like as in numbers, thus:

1. Range the quantities according to the dimensions of some letter, and set the root of the first term in the quotient.
2. Subtract the square of the root thus found, from the first term, and bring down the two next terms to the remainder for a dividend.
3. Divide the dividend by double the root, and set the result both in the quotient and divisor.
4. Multiply the divisor, thus increased, by the term last put in the quotient, and subtract the product from the dividend.

And so on, as in common arithmetic.

## EXAMPLES.

1. Extract the square root of  $x^4 - 4x^3 + 6x^2 - 4x + 1$ .  
 $x^4 - 4x^3 + 6x^2 - 4x + 1$  ( $x^2 - 2x + 1$  = root  
 $x^4$ )

$$\begin{array}{r} \overline{2x^2 - 2x)} \overline{- 4x^3 + 6x^2} \\ \quad - 4x^3 + 4x^2 \\ \hline \end{array}$$

$$\begin{array}{r} \overline{2x^2 - 4x + 1)} \overline{2x^2 - 4x + 1} \\ \quad 2x^2 - 4x + 1 \\ \hline \end{array}$$

2. Find the root of  $4a^4 + 12a^3x + 13a^2x^2 + 6ax^3 + x^4$ .  
 $4a^4 + 12a^3x + 13a^2x^2 + 6ax^3 + x^4$  ( $2a^2 + 3ax + x^2$ ).  
 $4a^4$ )

$$\begin{array}{r} \overline{4a^2 + 3ax)} \overline{12a^3x + 13a^2x^2} \\ \quad 12a^3x + 9a^2x^2 \\ \hline \end{array}$$

$$\begin{array}{r} \overline{4a^2 + 6ax + x^2)} \overline{4a^3x + 6ax^3 + x^4} \\ \quad 4a^3x + 6ax^3 + x^4 \\ \hline \end{array}$$

3. Required the square root of  $a^4 + 4a^3x + 6a^2x^2 + 4ax^3 + x^4$ .  
 Ans.  $a^2 + 2ax + x^2$ .

4. Required the square root of  $x^4 - 2x^3 + \frac{3}{2}x^2 - \frac{x}{2} + \frac{1}{16}$ .  
 Ans.  $x^2 - x + \frac{1}{4}$ .

5. It is required to find the square root of  $a^2 - b^2x^2$ .

Ans.  $a - \frac{b^2x^2}{2a} - \frac{b^4x^4}{8a^2} - \frac{b^6x^6}{16a^5} - \text{ &c.}$

### CASE III.

*To find the Roots of Powers in General.*

1. FIND the root of the first term, and place it in the quotient.

2. Subtract its power from that term, and bring down the second term for a dividend.

3. Involve the root, last found, to the next lower power, and multiply it by the index of the given power, for a divisor.

4. Divide the dividend by the divisor, and the quotient will be the next term of the root.

5. Involve the whole root to the power to be extracted, then subtract the power thus arising from the given power, and always divide the first term of the remainder by the divisor first found; and so on till the whole is finished \*.

### EXAMPLES.

1. To find the sq. root of  $a^4 - 2a^3x + 3a^2x^2 - 2ax^3 + x^4$ ,  
 $a^4 - 2a^3x + 3a^2x^2 - 2ax^3 + x^4$  (  $a^2 - ax + x^2$   
 $a^2$  )

$2a^2$  )  $- 2a^3x$

$a^4 - 2a^3x + a^2x^2$   $= (a^2 - ax)^2$

$2a^2$  )  $2a^2x^2$

$a^4 - 2a^3x + 2a^2x^2 - 2ax^3 + x^4$   $= (a^2 - ax + x^2)^2$

2. Find

\* As this method, in high powers, is generally thought too laborious, it may not be improper to observe, that the roots of compound quantities may sometimes be easily discovered, thus:

2. Find the cube root of  $x^6 + 6x^5 - 40x^3 + 96x - 64$ .

$$\begin{array}{r} x^6 + 6x^5 - 40x^3 + 96x - 64 \\ \hline x^6 \\ \hline \end{array}$$

$$\overline{3x^4})\ 6x^5$$

$$\overline{x^6 + 6x^5 + 12x^4 + 8x^3 = (x^2 + 2x)^3}$$

$$\overline{3x^4) - 12x^4}$$

$$\overline{x^6 + 6x^5 - 40x^3 + 96x - 64 = (x^2 + 2x - 4)^3.}$$

3. Required the square root of  $a^2 + 2ab + 2ac + b^2 + 2bc + c^2$ .  
Ans.  $a + b + c$ .

4. Required the cube root of  $x^6 - 6x^5 + 15x^4 - 20x^3 + 15x^2 - 6x + 1$ .  
Ans.  $x^2 - 2x + 1$ .

5. Required the biquadrate root of  $16a^4 - 96a^3x + 216a^2x^2 - 216ax^3 + 81x^4$ .  
Ans.  $2a - 3x$ .

6. Required the 5th root of  $32x^5 - 80x^4 + 80x^3 - 40x^2 + 10x - 1$ .  
Ans.  $2x - 1$ .

7. Required the square root of  $1 - x^2$ .

8. Required the cube root of  $1 - x^3$ .

---

1. Extract the roots of some of the most simple terms, and connect them together by the sign  $+$  or  $-$ , as may be judged most suitable for the purpose.

2. Involve the compound root, thus found, to the proper power; then, if it be the same with the given quantity, it is the root required.

3. But if it be found to differ only in some of the signs, change them from  $+$  to  $-$ , or from  $-$  to  $+$ , till its power agrees with the given one throughout.

Thus, in the 5th example, the root  $2a - 3x$ , is the difference of the roots of the first and last terms; and in the 3d example, the root  $a + b + c$  is the sum of the roots of the 1st, 4th, and 6th terms. The same may also be observed of the 6th example, where the root is found from the first and last terms.

## SURDS.

SURDS are such quantities as have no exact root, being usually expressed by fractional indices, or by means of the radical sign  $\sqrt{\phantom{x}}$ .

Thus,  $2^{\frac{1}{2}}$ , or  $\sqrt{2}$ , denotes the square root of 2; and  $3^{\frac{2}{3}}$  or  $\sqrt[3]{3^2}$ , the cube root of the square of 3; where the numerator shews the power to which the quantity is to be raised, and the denominator its root.

## PROBLEM I.

*To Reduce a Rational Quantity to the Form of a Surd.*

RAISE the quantity to a power equivalent to that denoted by the index of the surd; then over this new quantity place the radical sign, and it will be of the form required.

## EXAMPLES.

1. To reduce 3 to the form of the square root.

First,  $3 \times 3 = 3^2 = 9$ ; then  $\sqrt{9}$  is the answer.

2. To reduce  $2x^2$  to the form of the cube root.

First,  $2x^2 \times 2x^2 \times 2x^2 = (2x^2)^3 = 8x^6$ ;

then  $\sqrt[3]{8x^6}$  or  $(8x^6)^{\frac{1}{3}}$  is the answer.

3. Reduce 5 to the form of the cube root.

Anf.  $(125)^{\frac{1}{3}}$  or  $\sqrt[3]{125}$ .

4. Reduce  $\frac{1}{2}xy$  to the form of the square root.

Anf.  $\sqrt{\frac{1}{4}x^2y^2}$ .

5. Reduce 2 to the form of the 5th root. Anf.  $(32)^{\frac{1}{5}}$ .

6. Let  $a^{\frac{1}{2}}$  be reduced to the form of the 6th root.

7. Reduce  $a + b$  to the form of the square root,  
and  $a - b$  to the form of the cube root.

## PROBLEM II.

*To Reduce Quantities of Different Indices, to other equivalent ones, that shall have a Common Index.*

1. DIVIDE the indices of the quantities by the given index, and the quotients will be the new indices for those quantities.

2. Over

2. Over the said quantities, with their new indices, place the given index, and they will make the equivalent quantities required.

3. A common index may also be found by reducing the indices of the quantities to a common denominator; and involving each of them to the power denoted by its numerator.

## EXAMPLES.

1. Reduce  $15^{\frac{1}{4}}$  and  $9^{\frac{1}{6}}$  to equivalent quantities having the common index  $\frac{1}{2}$ .

$$\frac{\frac{1}{4}}{\frac{1}{2}} = \frac{\frac{1}{4}}{\frac{1}{2}} \times \frac{\frac{2}{1}}{\frac{2}{1}} = \frac{\frac{2}{4}}{\frac{1}{2}} = \frac{1}{2} \text{ the 1st index,}$$

$$\frac{\frac{1}{6}}{\frac{1}{2}} = \frac{\frac{1}{6}}{\frac{1}{2}} \times \frac{\frac{2}{1}}{\frac{2}{1}} = \frac{\frac{2}{6}}{\frac{1}{2}} = \frac{1}{3} \text{ the 2d index.}$$

Therefore  $(15^{\frac{1}{2}})^{\frac{1}{2}}$  and  $(9^{\frac{1}{2}})^{\frac{1}{2}}$  are the quantities required.

2. Reduce  $a^2$  and  $x^{\frac{1}{4}}$  to the same common index  $\frac{1}{3}$ .

$$\frac{\frac{1}{2}}{\frac{1}{3}} = \frac{\frac{1}{2}}{\frac{1}{3}} \times \frac{\frac{3}{1}}{\frac{3}{1}} = \frac{\frac{3}{2}}{\frac{1}{3}} = \frac{9}{2} \text{ the 1st index,}$$

$$\frac{\frac{1}{4}}{\frac{1}{3}} = \frac{\frac{1}{4}}{\frac{1}{3}} \times \frac{\frac{3}{1}}{\frac{3}{1}} = \frac{\frac{3}{4}}{\frac{1}{3}} = \frac{9}{4} \text{ the 2d index.}$$

Therefore  $(a^2)^{\frac{1}{3}}$  and  $(x^{\frac{1}{4}})^{\frac{1}{3}}$  are the quantities required.

3. Reduce  $3^{\frac{1}{2}}$  and  $2^{\frac{1}{3}}$  to the common index  $\frac{1}{6}$ .

Ansl.  $27^{\frac{1}{6}}$  and  $4^{\frac{1}{6}}$ .

4. Reduce  $a^{\frac{1}{2}}$  and  $b^{\frac{1}{4}}$  to the common index  $\frac{1}{8}$ .

Ansl.  $(a^4)^{\frac{1}{8}}$  and  $(b^2)^{\frac{1}{8}}$ .

5. Reduce  $a^{\frac{1}{n}}$  and  $b^{\frac{1}{m}}$  to the same radical sign.

Ansl.  $\sqrt[n]{a^m}$  and  $\sqrt[m]{b^n}$ .

6. Reduce  $(a + b)^{\frac{1}{2}}$  and  $(a - b)^{\frac{1}{3}}$  to a common index.

7. Reduce  $(a + b)^{\frac{1}{3}}$  and  $(a - b)^{\frac{1}{4}}$  to a common index.

## PROBLEM III.

*To Reduce Surds to their most Simple Terms \*.*

FIND the greatest power contained in the given surd, and set its root before the remaining quantities, with the proper radical sign between them.

\* When the given surd contains no exact power, it is already in its most simple terms.

## EXAMPLES.

1. To reduce  $\sqrt{48}$  to its most simple terms.

$$\sqrt{48} = \sqrt{16 \times 3} = \sqrt{16} \times \sqrt{3} = 4 \times \sqrt{3} = 4\sqrt{3},$$

the answer.

2. Required to reduce  $\sqrt[3]{108}$  to its most simple terms.

$$\sqrt[3]{108} = \sqrt[3]{27 \times 4} = \sqrt[3]{27} \times \sqrt[3]{4} = 3 \times \sqrt[3]{4} = 3\sqrt[3]{4},$$

the answer.

3. Reduce  $\sqrt{125}$  to its simplest terms. Anf.  $5\sqrt{5}$ .

4. Reduce  $\sqrt{\frac{5}{147}}$  to its simplest terms. Anf.  $\frac{5}{21}\sqrt{6}$ .

5. Reduce  $\sqrt[3]{243}$  to its simplest terms. Anf.  $3\sqrt[3]{9}$ .

6. Reduce  $\sqrt[3]{\frac{16}{81}}$  to its simplest terms. Anf.  $\frac{2}{3}\sqrt[3]{18}$ .

7. Reduce  $\sqrt{98a^2x}$  to its simplest terms. Anf.  $7a\sqrt{2x}$ .

8. Reduce  $\sqrt{x^3 - a^2x^2}$  to its most simple terms.

9. Reduce  $(a^3x + 3a^3x^2)^{\frac{1}{3}}$  to its most simple terms.

10. Reduce  $(32a^6 - 96a^5x)^{\frac{1}{3}}$  to its most simple terms.

## PROBLEM IV

*To add Surd Quantities together.*

1. REDUCE such quantities as have unlike indices to other equivalent ones, having a common index.

2. Bring all fractions to a common denominator, and reduce the quantities to their simplest terms, as in the last problem.

3. Then, if the surd part be the same in them all, annex it to the sum of the rational parts, with the sign of multiplication, and it will give the total sum required.

But if the surd part be not the same in all the quantities, they can only be added by the signs + and -.

## EXAMPLES.

1. It is required to add  $\sqrt{27}$  and  $\sqrt{48}$  together.

First,  $\sqrt{27} = \sqrt{9 \times 3} = 3\sqrt{3}$ ; and  $\sqrt{48} = \sqrt{16 \times 3} = 4\sqrt{3}$ ;  
Then,  $3\sqrt{3} + 4\sqrt{3} = (3 + 4)\sqrt{3} = 7\sqrt{3}$  = sum required.

2. It is required to add  $\sqrt[3]{500}$ , and  $\sqrt[3]{108}$  together.

First,  $\sqrt[3]{500} = \sqrt[3]{125 \times 4} = 5\sqrt[3]{4}$ ; and  $\sqrt[3]{108} = \sqrt[3]{27 \times 4} = 3\sqrt[3]{4}$ ;

Then,  $5\sqrt[3]{4} + 3\sqrt[3]{4} = (5 + 3)\sqrt[3]{4} = 8\sqrt[3]{4}$  = sum required.

3. Required

3. Required the sum of  $\sqrt{72}$  and  $\sqrt{128}$ . Anf.  $14\sqrt{2}$ .
4. Required the sum of  $\sqrt{27}$  and  $\sqrt{147}$ . Anf.  $10\sqrt{3}$ .
5. Required the sum of  $\sqrt{\frac{2}{3}}$  and  $\sqrt{\frac{27}{50}}$ . Anf.  $\frac{19}{10}\sqrt{6}$ .
6. Required the sum of  $\sqrt[3]{40}$  and  $\sqrt[3]{135}$ . Anf.  $5\sqrt[3]{5}$ .
7. Required the sum of  $\sqrt[3]{\frac{1}{4}}$  and  $\sqrt[3]{\frac{1}{32}}$ . Anf.  $\frac{3}{4}\sqrt[3]{2}$ .
8. Required the sum of  $2\sqrt{a^b b}$  and  $3\sqrt{64b^c x^d}$ .
9. Required the sum of  $9\sqrt{243}$  and  $10\sqrt{363}$ .
10. Required to find the sum of  $a^{\frac{1}{b}}$  and  $a^{\frac{1}{c}}$ .
11. Required the sum of  $\sqrt{27a^4x}$  and  $\sqrt{3a^2x}$ .

## PROBLEM V.

*To Subtract, or find the Difference of, Surd Quantities.*

PREPARE the quantities as in the last rule; then the difference of the rational parts annexed to the common surd, will give the difference of the surds required.

But if the quantities have no common surd, they can only be subtracted by means of the sign —.

## EXAMPLES.

1. Required to find the difference of  $\sqrt{448}$  and  $\sqrt{112}$ .  
First,  $\sqrt{448} = \sqrt{64 \times 7} = 8\sqrt{7}$ ; and  $\sqrt{112} = \sqrt{16 \times 7} = 4\sqrt{7}$ . Then  $8\sqrt{7} - 4\sqrt{7} = 4\sqrt{7}$  the difference required.
2. Required to find the difference of  $192^{\frac{1}{3}}$  and  $24^{\frac{1}{3}}$ .  
First,  $192^{\frac{1}{3}} = (64 \times 3)^{\frac{1}{3}} = 4 \cdot 3^{\frac{1}{3}}$ ; and  $24^{\frac{1}{3}} = (8 \times 3)^{\frac{1}{3}} = 2 \cdot 3^{\frac{1}{3}}$ . Then  $4 \cdot 3^{\frac{1}{3}} - 2 \cdot 3^{\frac{1}{3}} = 2 \cdot 3^{\frac{1}{3}}$  the difference required.
3. Required the diff. of  $2\sqrt{50}$  and  $\sqrt{18}$ . Anf.  $7\sqrt{2}$ .
4. Required the diff. of  $320^{\frac{1}{3}}$  and  $40^{\frac{1}{3}}$ . Anf.  $2 \cdot 5^{\frac{1}{3}}$ .
5. Required the diff. of  $\sqrt{\frac{2}{3}}$  and  $\sqrt{\frac{5}{27}}$ . Anf.  $\frac{4}{3}\sqrt{15}$ .
6. Required the diff. of  $\sqrt[3]{\frac{2}{3}}$  and  $\sqrt[3]{\frac{9}{32}}$ . Anf.  $\frac{1}{12}\sqrt[3]{18}$ .
7. Find the difference of  $\sqrt{80a^4x}$  and  $\sqrt{20a^2x^5}$ .  
Anf.  $(4a^2 - 2ax)\sqrt{5x}$ .
8. Required the difference of  $8\sqrt[3]{a^3b}$  and  $\sqrt[3]{a^6b}$ .
9. Required the difference of  $x^{\frac{1}{n}}$  and  $x^{\frac{1}{m}}$ .

## PROBLEM

## PROBLEM VI.

*To Multiply Surd Quantities together.*

REDUCE the surds to the same index; next multiply the rational quantities together, and the surds together; then the one product annexed to the other will give the whole product required; which may be reduced to its most simple terms by Problem 3.

## EXAMPLES.

1. Required to find the product of  $3\sqrt{8}$  and  $2\sqrt{6}$ .

Here,  $3 \times 2 \times \sqrt{8} \times \sqrt{6} = 6\sqrt{8 \times 6} = 6\sqrt{48} = 6\sqrt{16 \times 3} = 6 \times 4 \times \sqrt{3} = 24\sqrt{3}$ , the product required.

2. Required to find the product of  $\frac{1}{2}\sqrt{\frac{2}{3}}$  and  $\frac{2}{3}\sqrt{\frac{5}{6}}$ .

Here  $\frac{1}{2} \times \frac{2}{3}\sqrt{\frac{2}{3}} \times \sqrt{\frac{5}{6}} = \frac{3}{8} \times \sqrt{\frac{10}{18}} = \frac{3}{8} \times \sqrt{\frac{5}{9}} = \frac{3}{8} \times \frac{1}{3} \times \sqrt{15} = \frac{3}{24}\sqrt{15} = \frac{1}{8}\sqrt{15}$  the product required.

3. Required the product of  $5\sqrt{8}$  and  $3\sqrt{5}$ . Ans.  $30\sqrt{10}$ .

4. Required the product of  $\frac{1}{2}\sqrt{6}$  and  $\frac{2}{3}\sqrt{18}$ . Ans.  $\sqrt{4}$ .

5. To find the product of  $\frac{2}{3}\sqrt{\frac{1}{8}}$  and  $\frac{3}{4}\sqrt{\frac{7}{15}}$ . Ans.  $\frac{1}{40}\sqrt{35}$ .

6. Required the product of  $\sqrt[3]{18}$  and  $5\sqrt[3]{4}$ . Ans.  $10\sqrt[3]{9}$ .

7. Required the product of  $a^{\frac{1}{3}}$  and  $a^{\frac{2}{3}}$ . Ans.  $(a^2)^{\frac{1}{3}}$  or  $a$ .

8. Required the product of  $(x + y)^{\frac{1}{2}}$  and  $(x + y)^{\frac{1}{3}}$ .

9. Required the product of  $x + \sqrt{y}$  and  $x - \sqrt{y}$ .

10. Required the product of  $(a + \sqrt{b})^{\frac{1}{2}}$ , and  $(a - \sqrt{b})^{\frac{1}{2}}$ .

11. Required the product of  $x^{\frac{1}{n}}$  and  $x^{\frac{1}{m}}$ .

12. Required the product of  $x^{\frac{1}{m}}$  and  $y^{\frac{1}{n}}$ .

## PROBLEM VII.

*To Divide one Surd Quantity by another.*

REDUCE the surds to the same index; then take the quotient of the rational quantities, and annex it to the quotient of the surds, and it will give the whole quotient required; which may be reduced to its most simple terms as before in multiplication.

## EXAMPLES.

## EXAMPLES.

1. It is required to divide  $8\sqrt[3]{108}$  by  $2\sqrt[3]{6}$ .

$$8 \div 2 \cdot \sqrt{(108 \div 6)} = 4\sqrt[3]{18} = 4\sqrt[3]{(9 \times 2)} = 4 \times 3 \\ \sqrt{2} = 12\sqrt[3]{2}, \text{ the quotient required.}$$

2. It is required to divide  $8\sqrt[3]{512}$  by  $4\sqrt[3]{2}$ .

$$8 \div 4 = 2, \text{ and } 512^{\frac{1}{3}} \div 2^{\frac{1}{3}} = 256^{\frac{1}{3}} = 4 \cdot 4^{\frac{1}{3}};$$

Therefore  $2 \times 4 \times 4^{\frac{1}{3}} = 8 \cdot 4^{\frac{1}{3}} = 8\sqrt[3]{4}$ , is the quot. required.

3. Let  $6\sqrt[3]{100}$  be divided by  $3\sqrt[3]{2}$ . Anf.  $10\sqrt[3]{2}$ .

4. Let  $4\sqrt[3]{1000}$  be divided by  $2\sqrt[3]{4}$ . Anf.  $10\sqrt[3]{2}$ .

5. Let  $\frac{3}{4}\sqrt[3]{\frac{1}{15}}$  be divided by  $\frac{3}{5}\sqrt[3]{\frac{1}{5}}$ . Anf.  $\frac{1}{8}\sqrt[3]{3}$ .

6. Let  $\frac{5}{7}\sqrt[3]{\frac{2}{3}}$  be divided by  $\frac{2}{5}\sqrt[3]{\frac{3}{4}}$ . Anf.  $\frac{2}{5}\sqrt[3]{3}$ .

7. Let  $\frac{2}{5}\sqrt{a}$ , or  $\frac{2}{3}a^{\frac{1}{2}}$ , be divided by  $\frac{3}{4}a^{\frac{1}{3}}$ . Anf.  $\frac{8}{15}a^{\frac{1}{6}}$ .

8. Let  $a^{\frac{2}{3}}$  be divided by  $a^{\frac{4}{3}}$ .

9. Let the quantity  $x^{\frac{1}{n}}$  be divided by the quantity  $x^{\frac{1}{m}}$ .

10. Let  $x^2 - xd - b + d\sqrt{b}$  be divided by  $x - \sqrt{b}$ .

## PROBLEM VIII.

*To Involve or Raise Surd Quantities to any Power.*

MULTIPLY the index of the quantity by the index of the power to which it is to be raised, and to the result annex the power of the rational parts, and it will give the power required.

## EXAMPLES.

1. It is required to find the square of  $\frac{2}{3}a^{\frac{1}{3}}$ .

First,  $(\frac{2}{3})^2 = \frac{2}{3} \times \frac{2}{3} = \frac{4}{9}$ , and  $(a^{\frac{1}{3}})^2 = a^{\frac{1}{3} \times 2} = a^{\frac{2}{3}} = (a^2)^{\frac{1}{3}}$ :

There.  $(\frac{2}{3}a^{\frac{1}{3}})^2 = \frac{4}{9}(a^2)^{\frac{1}{3}} = \frac{4}{9}\sqrt[3]{a^2}$ , is the square required.

2. It is required to find the cube of  $\frac{5}{7}\sqrt{7}$ .

First,  $(\frac{5}{7})^3 = \frac{5}{7} \times \frac{5}{7} \times \frac{5}{7} = \frac{125}{343}$ , and  $(7^{\frac{1}{2}})^3 = 7^{\frac{3}{2}} = (7^3)^{\frac{1}{2}}$ :

Theref.  $(\frac{5}{7}\sqrt{7})^3 = \frac{125}{343}(7^3)^{\frac{1}{2}} = \frac{125}{343}(343)^{\frac{1}{2}}$ , the cube required.

3. Required the square of  $3\sqrt[3]{3}$ . Anf.  $9\sqrt[3]{9}$ .

4. Required the cube of  $2^{\frac{1}{2}}$ , or  $\sqrt{2}$ . Anf.  $2\sqrt{2}$ .

5. Required the 4th power of  $\frac{1}{6}\sqrt{6}$ . Anf.  $\frac{1}{36}$ .

6. It

6. It is required to find the  $n$ th power of  $a^{\frac{1}{m}}$ .
7. It is required to find the square of  $3 + \sqrt{5}$ .
8. It is required to find the cube of  $2x - 3\sqrt{y}$ .

## PROBLEM IX.

*To Extract the Roots of Surd Quantities\*.*

DIVIDE the index of the given quantity by the index of the root to be extracted; then to the result annex the root of the rational part, and it will give the root required.

## EXAMPLES.

1. It is required to find the square root of  $9\sqrt[3]{3}$ .  
First,  $\sqrt{9} = 3$ , and  $(3^{\frac{1}{3}})^{\frac{1}{2}} = 3^{\frac{1}{3} \div 2} = 3^{\frac{1}{6}}$ ;  
therefore  $(9\sqrt[3]{3})^{\frac{1}{2}} = 3 \cdot 3^{\frac{1}{6}}$ , is the square root required.
2. It is required to find the cube root of  $\frac{1}{8}\sqrt{2}$ .  
First,  $\sqrt[3]{\frac{1}{8}} = \frac{1}{2}$ , and  $(\sqrt{2})^{\frac{1}{3}} = 2^{\frac{1}{2} \div 3} = 2^{\frac{1}{6}}$ ;  
therefore  $(\frac{1}{8}\sqrt{2})^{\frac{1}{3}} = \frac{1}{2} \cdot 2^{\frac{1}{6}}$ , is the cube root required.
3. Required the square root of  $10^3$ . Anf.  $10\sqrt{10}$ .
4. Required the cube root of  $\frac{8}{27}a^3$ . Anf.  $\frac{2}{3}a$ .
5. Required the 4th root of  $3x^2$ . Anf.  $3^{\frac{1}{4}} \cdot x^{\frac{1}{2}}$ .
6. It is required to find the  $n$ th root of  $x^m$ .
7. Required the square root of  $x^2 - 4x\sqrt{a} + 4a$ .

\* The square root of a binomial or residual surd,  $a + b$ , or  $a - b$ , may be found thus: Take  $\sqrt{a^2 - b^2} = d$ ;  
then  $\sqrt{a + b} = \sqrt{\frac{a + d}{2}} + \sqrt{\frac{a - d}{2}}$ ;  
and  $\sqrt{a - b} = \sqrt{\frac{a + d}{2}} - \sqrt{\frac{a - d}{2}}$ .  
Thus, the square root of  $8 + 2\sqrt{7} = 1 + \sqrt{7}$ ;  
and the square root of  $3 - \sqrt{8} = \sqrt{2} - 1$ .  
But for the cube, or any higher root, no general rule is given.

## INFINITE SERIES.

AN Infinite Series is formed from a vulgar fraction, having a compound denominator, or by extracting the root of a surd quantity; and is such as, being continued, would run on infinitely, in the manner of a continued decimal fraction.

But, by obtaining a few of the first terms, the law of the progression will be manifest; so that the series may be continued, without actually performing the whole operation.

## PROBLEM I.

*To Reduce Fractional Quantities into Infinite Series.*

DIVIDE the numerator by the denominator, as in common division; and the operation continued, as far as may be thought necessary, will give the series required.

## EXAMPLES.

1. To change  $\frac{ax}{a-x}$  into an infinite series.

$$a - x \quad ) \ ax \dots ( \quad x + \frac{x^2}{a} + \frac{x^3}{a^2} + \frac{x^4}{a^3} + \&c.$$

$$\frac{ax - x^2}{x^2}$$

$$x^2 - \frac{x^3}{a}$$

$$\frac{x^3}{a}$$

$$\frac{x^3}{a} - \frac{x^4}{a^2}$$

$$\frac{x^4}{a^2}$$

$$\frac{x^4}{a^2} - \frac{x^5}{a^3}$$

$$\frac{x^5}{a^3}$$

$$\frac{x^5}{a^3}, \&c.$$

2. Let  $\frac{1}{1+x}$  be changed into an infinite series.

$$1+x) \overline{1 \dots \dots (1-x+x^2-x^3+x^4-\&c.)}$$

$$\begin{array}{r} 1+x \\ -x \\ \hline -x-x^2 \\ \hline x^2 \\ -x^2+x^3 \\ \hline -x^3-x^4 \\ \hline x^4 \end{array}$$

3. Let  $\frac{b}{a+x}$  be converted into an infinite series.

$$\text{Ans. } \frac{b}{a} \times \left(1 - \frac{x}{a} + \frac{x^2}{a^2} - \frac{x^3}{a^3} + \&c.\right)$$

4. Let  $\frac{b}{a-x}$  be expanded into an infinite series.

$$\text{Ans. } \frac{b}{a} \times \left(1 + \frac{x}{a} + \frac{x^2}{a^2} + \frac{x^3}{a^3} + \&c.\right)$$

5. Let  $\frac{1+x}{1-x}$  be changed into an infinite series.

$$\text{Ans. } 1 + 2x + 2x^2 + 2x^3 + 2x^4 + \&c.$$

6. Let  $\frac{a^2}{(a+x)^2}$  be converted into an infinite series.

$$\text{Ans. } 1 - \frac{2x}{a} + \frac{3x^2}{a^2} - \frac{4x^3}{a^3} + \&c.$$

7. Let  $\frac{1}{2}$ , or its equal  $\frac{1}{1+1}$ , be expanded into an infinite series.

### PROBLEM II.

*To Reduce a Compound Surd into an Infinite Series.*

EXTRACT the root as in common arithmetic, and the operation, continued as far as may be thought necessary, will give the series required \*.

\* This rule is chiefly of use in extracting the square root, the operation being too tedious for the higher powers.

## EXAMPLES.

1. Extract the root of  $a^2 + x^2$  in an infinite series.

$$\begin{aligned}
 & a^2 + x^2 \left( a + \frac{x^2}{2a} - \frac{x^4}{8a^3} + \frac{x^6}{16a^5} - \frac{5x^8}{128a^7} \text{ &c.} \right. \\
 & \left. 2a + \frac{x^2}{2a} \right) x^2 \\
 & \quad x^2 + \frac{x^4}{4a^2} \\
 & \quad 2a + \frac{x^2}{a} - \frac{x^4}{8a^3} - \frac{x^4}{4a^2} \\
 & \quad - \frac{x^4}{4a^2} - \frac{x^5}{8a^4} + \frac{x^3}{64a^6} \\
 & \quad 2a + \frac{x^2}{a} - \frac{x^4}{4a^2}, \quad \text{&c.)} \quad \frac{x^6}{8a^4} - \frac{x^8}{64a^6} \\
 & \quad \frac{x^6}{8a^4} + \frac{x^8}{16a^6} \text{ &c.} \\
 & \quad \underline{- \frac{5x^8}{64a^6}, \text{ &c.}}
 \end{aligned}$$

2. Let  $\sqrt{1 + 1}$  be expanded into an infinite series.

$$\text{Ans. } 1 + \frac{1}{2} - \frac{1}{8} + \frac{1}{16} - \frac{1}{32} \text{ &c.}$$

3. Let  $\sqrt{a^2 - x^2}$  be changed into an infinite series.

$$\text{Ans. } a - \frac{x^2}{2a} - \frac{x^4}{8a^3} - \frac{x^6}{16a^5} \text{ &c.}$$

4. Let  $\sqrt[3]{1 - x^3}$  be converted into an infinite series.

$$\text{Ans. } 1 - \frac{x^3}{3} - \frac{x^6}{9} - \frac{5x^9}{81} \text{ &c.}$$

5. Let  $\sqrt{a^2 + b}$  be changed into an infinite series.

6. Expand  $\sqrt{a^2 - 2bx - x^2}$  to an infinite series.

## PROBLEM III.

To Reduce a Binomial Surd into an Infinite Series; or to Extract any Root of a Binomial\*.

SUBSTITUTE the particular letters of the binomial, with their proper signs, in the following general form, and it will give the root required; observing that  $P$  is the first term,  $Q$  the second term divided by the first,  $\frac{m}{n}$  the index of the power or root; and  $A, B, C, D, \&c.$ , the foregoing terms with their proper signs:

$$\frac{m}{P+Q^{\frac{m}{n}}} = P^{\frac{m}{n}} + \frac{m}{n} A Q + \frac{m-n}{2n} B Q^2 + \frac{m-2n}{3n} C Q^3 + \&c.$$

## EXAMPLES.

1. To extract the sq. root of  $r^2 - x^2$ , in an infinite series.

Here  $P = r^2, Q = -\frac{x^2}{r^2}$ , and  $\frac{m}{n} = \frac{1}{2}$ : therefore

$$P^{\frac{m}{n}} = (r^2)^{\frac{1}{2}} = (r^2)^{\frac{1}{2}} = r = A,$$

$$\frac{m}{n} A Q = \frac{1}{2} \times r \times -\frac{x^2}{r^2} = -\frac{x^2}{2r} = B;$$

$$\frac{m-n}{2n} B Q = \frac{1-2}{4} \times -\frac{x^2}{2r} \times -\frac{x^2}{r^2} = -\frac{x^4}{2.4r^3} = C,$$

$$\frac{m-2n}{3n} C Q = \frac{1-4}{6} \times -\frac{x^4}{2.4r^3} \times -\frac{x^2}{r^2} = -\frac{3x^6}{2.4.6r^5} = D,$$

$$\text{Hence } r - \frac{x^2}{2r} - \frac{x^4}{2.4r^3} - \frac{3x^6}{2.4.6r^5} - \&c, \text{ or}$$

$$r - \frac{x^2}{2r} - \frac{x^4}{8r^3} - \frac{x^6}{16r^5} - \frac{5x^8}{128r^7} \&c, \text{ is the series required.}$$

2. To find the value of  $\frac{1}{(a+b)^2}$ , or its equal  $(a+b)^{-2}$ , in an infinite series.

\* Note. Any surd may be taken from the denominator of a fraction and placed in the numerator, and vice versa, by only changing the sign of its index. Thus,

$$\frac{1}{x^2} = 1 \times x^{-2}; \text{ and } \frac{1}{(a+b)^2} = 1 \times (a+b)^{-2} \text{ or } (a+b)^{-2}; \text{ and}$$

$$\frac{a^2}{(a+x)^2} = a^2 (a+x)^{-2}; \text{ and } \frac{x^{\frac{1}{2}}}{x^{\frac{1}{3}}} = x^{\frac{1}{2}} \times x^{-\frac{1}{3}}; \text{ also } \frac{(a^2+x^2)^{\frac{1}{2}}}{(a^2-x^2)^{\frac{1}{2}}} \\ = (a^2+x^2)^{\frac{1}{2}} \times (a^2-x^2)^{-\frac{1}{2}}.$$

Here  $P = a$ ,  $Q = \frac{b}{a} = a^{-1}b$ , and  $\frac{m}{n} = \frac{-2}{1} = -2$ ; therefore

$$\frac{m}{p^n} = (a)^{-2} = a^{-2} = \frac{1}{a^2} = A,$$

$$\frac{m}{n}AQ = -2 \times \frac{1}{a^2} \times \frac{b}{a} = -\frac{2b}{a^3} = -2a^{-3}b = B,$$

$$\frac{m-n}{2n}BQ = -\frac{3}{2} \times -\frac{2b}{a^3} \times \frac{b}{a} = \frac{3b^2}{a^4} = 3a^{-4}b^2 = C,$$

$$\frac{m-2n}{3n}CQ = -\frac{4}{3} \times \frac{3b^2}{a^4} \times \frac{b}{a} = -\frac{4b^3}{a^5} = -4a^{-5}b^3 = D,$$

Hence  $a^{-2} - 2a^{-3}b + 3a^{-4}b^2 - 4a^{-5}b^3 + \&c$ , or

$\frac{1}{a^2} - \frac{2b}{a^3} + \frac{3b^2}{a^4} - \frac{4b^3}{a^5} + \frac{5b^4}{a^6} + \&c$ , is the series required.

3. To find the value of  $\frac{r^2}{r+x}$ , in an infinite series.

$$\text{Ans. } r - x + \frac{x^2}{r} - \frac{x^3}{r^2} + \frac{x^4}{r^3}, \&c.$$

4. To find the value of  $\frac{1}{(a^2-x^2)^{\frac{1}{2}}}$  in an infinite series.

$$\text{Ans. } \frac{1}{a} + \frac{x^2}{2a^3} + \frac{3x^4}{8a^5} + \frac{15x^6}{48a^7}, \&c.$$

5. To find the value of  $\frac{a^2}{(a+x)^2}$  in an infinite series.

$$\text{Ans. } 1 - \frac{2x}{a} + \frac{3x^2}{a^2} - \frac{4x^3}{a^3} + \frac{5x^4}{a^4}, \&c.$$

6. To find the value of  $(a^2+b)^{\frac{1}{2}}$  in an infinite series.

$$\text{Ans. } a + \frac{b}{2a} - \frac{b^2}{8a^3} + \frac{b^3}{16a^5} - \frac{5b^4}{128a^7}, \&c.$$

7. Find the value of  $(a^2-x^2)^{\frac{1}{3}}$  in an infinite series.

$$\text{Ans. } a^{\frac{2}{3}} \times (1 - \frac{x^2}{5a^2} - \frac{2x^4}{25a^4} - \frac{6x^6}{125a^6}, \&c.)$$

8. To find the value of  $(a^3-b)^{\frac{1}{3}}$  in an infinite series.

$$\text{Ans. } a - \frac{b}{3a^2} - \frac{b^2}{9a^5} - \frac{5b^3}{81a^8} - \frac{10b^4}{243a^{11}}, \&c.$$

9. To find the square root of  $\frac{a^2+x^2}{a^2-x^2}$  in an infinite series.

$$\text{Ans. } 1 + \frac{x^2}{a^2} + \frac{x^4}{2a^4} + \frac{x^6}{2a^6}, \&c.$$

10. Find

10. Find the cube root of  $\frac{a^3}{(a^2 + x^2)^2}$  in an infinite series.

$$\text{Ans. } \frac{1}{a^{\frac{2}{3}}} \times \left( 1 - \frac{2x^2}{3a^2} + \frac{5x^4}{9a^4} - \frac{40x^6}{81a^6}, \text{ &c.} \right)$$

11. Find the value of  $\frac{ax}{a^2 - ax + x^2}$  in an infinite series.

$$\text{Ans. } \frac{x}{a} + \frac{x^2}{a^2} - \frac{x^4}{a^4} + \frac{x^5}{a^5}, \text{ &c.}$$

## ARITHMETICAL PROPORTION.

ARITHMETICAL PROPORTION is the relation which two quantities, of the same kind, bear to each other, in respect to their difference.

Four quantities are said to be in Arithmetical Proportion, when the difference between the first and second is equal to the difference between the third and fourth.

Thus, 3, 7, 12, 16, and  $a, a+b, c, c+b$ , are arithmetically proportional.

Arithmetical Progression is when a series of quantities either increase or decrease by the same common difference.

Thus, 1, 3, 5, 7, 9, 11, &c, and  $a, a+b, a+2b, a+3b, a+4b, a+5b$ , &c, are series in arithmetical progression, whose common differences are 2 and  $b$ .

The most useful part of arithmetical proportion is contained in the following theorems :

1. When four quantities are in Arithmetical Proportion, the sum of the two extremes is equal to the sum of the two means.

Thus, if 2, 5, 7, 10, and  $a, b, c, d$ , be in arithmetical proportion ; then is  $2+10=5+7$ , and  $a+d=b+c$ .

2. In any continued arithmetical progression, the sum of the two extremes is equal to the sum of any two terms which are equally distant from them.

Thus,

Thus, if the series be 2, 4, 6, 8, 10, 12, &c.

$$\text{Then } 2 + 12 = 4 + 10 = 6 + 8 = 14.$$

3. The last term of any arithmetical series, is equal to the sum, or difference, of the first term, and the product of the common difference multiplied by the number of terms less one; according as the series is increasing or decreasing.

Thus, the 20th term of 2, 4, 6, 8, 10, 12, &c, is =  $2 + 2(20 - 1) = 2 + 2 \times 19 = 2 + 38 = 40$ .

And the  $n$ th term of  $a, a - x, a - 2x, a - 3x, a - 4x, \dots$ , &c, is =  $a - (n - 1) \times x = a - (n - 1) \cdot x$ .

4. The sum of any series of quantities in arithmetical progression, is equal to the sum of the two extremes multiplied by half the number of terms.

Thus, the sum of 1, 2, 3, 4, 5, 6, &c, continued to the 20th term, is =  $\frac{(1 + 20) \times 20}{2} = \frac{21 \times 20}{2} = 21 \times 10 = 210$ .

And the sum of  $n$  terms of  $a, a + x, a + 2x, a + 3x, \dots, a + mx$ , is =  $(a + a + mx) \cdot \frac{n}{2} = (a + \frac{1}{2}mx) n = (a + \frac{n-1}{2}x) n$ .

### EXAMPLES.

1. The first term of an increasing arithmetical series is 3, the common difference 2, and the number of terms 20; required the sum of the series?

First,  $3 + 2 \times (20 - 1) = 3 + 2 \times 19 = 3 + 38 = 41$ , is the last term.

Then  $(3 + 41) \times \frac{20}{2} = 44 \times 10 = 440$ , the sum required.

2. The first term of a decreasing arithmetical series is 100, the common difference 3, and the number of terms 34; required the sum of the series?

First,  $100 - 3 \cdot (34 - 1) = 100 - 3 \cdot (33) = 100 - 99 = 1$ , is the last term.

Then  $(100 + 1) \times \frac{34}{2} = 101 \times 17 = 1717$ , is the sum required.

3. Required the sum of the natural numbers 1, 2, 3, 4, 5, &c, &c, continued to 1000 terms? Ans. 500000.

4. \* Required the sum of the odd numbers 1, 3, 5, 7, 9, &c, continued to 101 terms? Anf. 10201.

5. How many strokes do the clocks of Venice, which go on to 24 o'clock, strike in the compass of a day? Anf. 300.

6. The first term of a decreasing arithmetical series is 10, the common difference  $\frac{1}{3}$ , and the number of terms 21; required the sum of the series? Anf. 140.

7. One hundred stones being placed on the ground, in a straight line, at the distance of 2 yards from each other; how far will a person travel, who shall bring them one by one to a basket, which is placed 2 yards from the first stone?

Anf. 11 miles and 840 yards.

## APPLICATION OF ARITHMETICAL PROGRESSION TO MILITARY AFFAIRS.

### QUESTION I.

A TRIANGULAR Battalion †, consisting of thirty ranks, in which the first rank is formed of one man only, the second

\* The sum of any number of terms ( $n$ ) of the arithmetical series of odd numbers 1, 3, 5, 7, 9, &c, is equal to the square ( $n^2$ ) of that number.

That is, if 1, 3, 5, 7, 9, &c, be the numbers, then will  $1^2, 2^2, 3^2, 4^2, 5^2, \dots$  be the sums of 1, 2, 3, &c, terms.

For  $0 + 1$ , or the sum of 1 term = 1 or  $1^2$ ,

$1 + 3$ , or the sum of 2 terms = 4 or  $2^2$ ,

$4 + 5$ , or the sum of 3 terms = 9 or  $3^2$ ,

$9 + 7$ , or the sum of 4 terms = 16 or  $4^2$ , &c.

Whence it is plain, that, let  $n$  be any number whatever, the sum of  $n$  terms will be  $n^2$ .

See more on Arithmetical Proportion in the Arithmetic, p. 111.

† By triangular battalion, is to be understood, a body of troops ranged in the form of a triangle, in which the ranks exceed each other by an equal number of men: if the first rank consist of one man only, and the difference between the ranks be also one, then

second of 3, the third of 5; and so on: What is the strength of such a triangular battalion?

Answer, 900 men.

### QUESTION II.

A detachment having 12 successive days to march, with orders to advance the first day only 2 leagues, the second  $3\frac{1}{2}$ , and so on, increasing  $1\frac{1}{2}$  league each day's march: What is the length of the whole march, and what is the last day's march?

Answer, the last day's march is  $18\frac{1}{2}$  leagues, and 123 leagues is the length of the whole march.

### QUESTION III.

A brigade of sappers\*, having carried on 15 yards of sap the first night, the second only 13 yards, and so on, decreasing 2 yards every night, till at last they carried on in one night only 3 yards: What is the number of nights they were employed; and what is the whole length of the sap?

Answer, they were employed 7 nights, and the length of the whole sap was 63 yards.

its form is that of an equilateral triangle; and when the difference between the ranks is more than one, its form may then be an isosceles or scalene triangle. The practice of forming troops in this order, which is now laid aside, was formerly held in greater esteem than forming them in a solid square, as admitting of a greater front, especially when the troops were to make simply a stand on all sides,

\* A brigade of sappers, consists generally of 8 men, divided equally into two parties. While one of these parties is advancing the sap, the other is furnishing the gabions, fascines, and other necessary implements: and when the first party is tired, the second takes its place, and so on, till each man in turn has been at the head of the sap. A sap is a small ditch, between 3 and 4 feet in breadth and depth; and is distinguished from the trench by its breadth only, the trench having between 10 and 15 feet breadth. As an encouragement to sappers, the pay for all the work carried on by the whole brigade, is given to the survivors.

## QUESTION IV.

A number of gabions\* being given to be placed in six ranks, one above the other, in such a manner as that each rank exceeding one another equally, the first may consist of 4 gabions, and the last of 9: What is the number of gabions in the six ranks; and what is the difference between each rank?

Answer, the difference between the ranks will be 1, and the number of gabions in the six ranks will be 39.

## QUESTION V.

Two detachments, distant from each other 37 leagues, and both designing to occupy an advantageous post equi-distant from each other's camp, set out at different times; the first detachment increasing every day's march one league and a half, and the second detachment increasing each day's march 2 leagues: both the detachments arrive at the same time; the first after five days' march, and the second after four days' march: What is the number of leagues marched by each detachment each day?

The progression  $\frac{7}{8}, 2\frac{2}{5}, 3\frac{7}{10}, 5\frac{2}{5}, 6\frac{7}{10}$ , answers the conditions of the first detachment: and the progression  $1\frac{1}{2}, 3\frac{1}{2}, 5\frac{1}{2}, 7\frac{1}{2}$ , answers the conditions of the second detachment.

## QUESTION VI.

A deserter, in his flight, travelling at the rate of 8 leagues a day; and a detachment of dragoons being sent after him, with orders to march the first day only 2 leagues, the second 5 leagues, the third 8 leagues, and so on: What is the number of days necessary for the detachment to overtake the deserter, and what will be the number of leagues marched before he is overtaken?

Answer, 5 days are necessary to overtake him; and, consequently, 40 leagues will be the extent of the march.

\* Gabions are baskets, open at both ends, made of ozier twigs, and of a cylindrical form: those made use of at the trenches are two feet wide, and about three feet high; which, being filled with earth, serve as a shelter from the enemy's fire: and those made use of to construct batteries, are generally higher and broader. There is another sort of gabion, made use of to raise a low parapet: its height is from 1 to 2 feet, and 1 foot wide at top, but somewhat less at bottom, to give room for placing the muzzle of a firelock between them: these gabions serve instead of sand bags. A sand bag is generally made to contain about a cubical foot of earth.

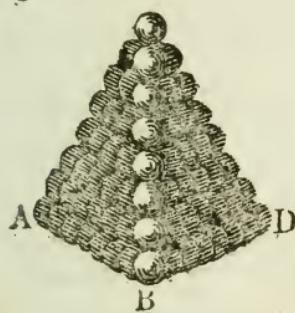
## QUESTION VII.

A convoy\* distant 35 leagues, having orders to join its camp, and to march at the rate of 5 leagues per day; its escort departing at the same time, with orders to march the first day only half a league, and the last day  $9\frac{1}{2}$  leagues; and both the escort and convoy arriving at the same time: At what distance is the escort from the convoy at the end of each march?

## OF COMPUTING SHOT OR SHELLS IN A FINISHED PILE.

SHOT and Shells are generally piled in three different forms, called triangular, square, or oblong piles, according as their base is either a triangle, a square, or a rectangle.

Fig. 1. C



G

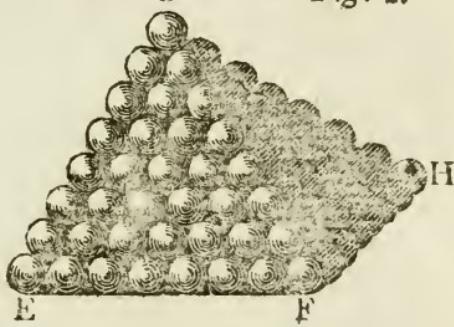


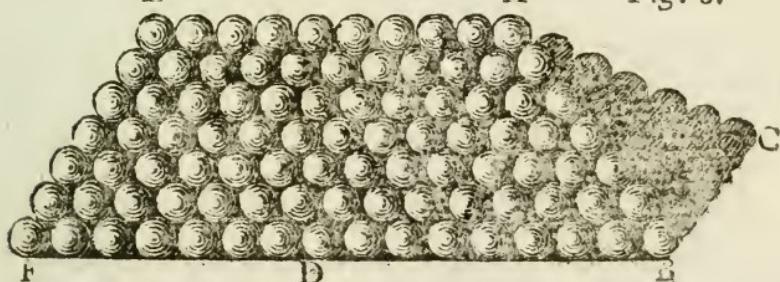
Fig. 2.

ABCD, fig. 1, is a triangular pile,  
EFGH, fig. 2, is a square pile.

E

A

Fig. 3.



ABCDEF, fig. 3, is an oblong pile.

\* By convoy is generally meant a supply of ammunition or provisions, conveyed to a town or army. The body of men that guard this supply, is called escort.

A triangular

A triangular pile is formed by the continual laying of triangular horizontal courses of shot one above another, in such a manner, as that the sides of these courses, called rows, decrease by unity from the bottom row to the top row, which ends always in 1 shot.

A square pile is formed by the continual laying of square horizontal courses of shot one above another, in such a manner, as that the sides of these courses decrease by unity from the bottom to the top row, which ends also in 1 shot.

In the triangular and the square piles, the sides or faces being equilateral triangles, the shot contained in those faces form an arithmetical progression, having for first term unity, and for last term and number of terms, the shot contained in the bottom row; for the number of horizontal rows, or the number counted on one of the angles from the bottom to the top, is always equal to those counted on one side in the bottom: the sides or faces in either the triangular or square piles, are called arithmetical triangles; and the numbers contained in these, are called triangular numbers: ABC fig. 1, EFG fig. 2, are arithmetical triangles.

The oblong pile may be conceived as formed from the square pile ABCD; to one side or face of which, as AD, a number of arithmetical triangles equal to the face have been added: and the number of arithmetical triangles added to the square pile, by means of which the oblong pile is formed, is always one less than the shot in the top row; or, which is the same, equal to the difference between the bottom row of the greater side and that of the lesser.

#### QUESTION VIII.

To find the shot in the triangular pile ABCD, fig. 1, the bottom row AB consisting of 8 shot.

#### SOLUTION.

The proposed pile consisting of 8 horizontal courses, each of which forms an equilateral triangle; that is, the shot contained in these being in an arithmetical progression, of which the first and last term, as also the number of terms, are known; it follows, that the sum of these particular courses, or of the 8 progressions, will be the shot contained in the proposed pile; then

The

The shot of the first or lower } triangular course will be }	$8 + 1 \times 4 = 36$
the second - - - -	$7 + 1 \times 3\frac{1}{2} = 28$
the third - - - -	$6 + 1 \times 3 = 21$
the fourth - - - -	$5 + 1 \times 2\frac{1}{2} = 15$
the fifth - - - -	$4 + 1 \times 2 = 10$
the sixth - - - -	$3 + 1 \times 1\frac{1}{2} = 6$
the seventh - - - -	$2 + 1 \times 1 = 3$
the eighth - - - -	$1 + 1 \times \frac{1}{2} = 1$

Total - 120 shot in  
the pile proposed.

## QUESTION IX.

To find the shot of the square pile EFGH, fig. 2, the bottom row EF consisting of 8 shot.

## SOLUTION.

The bottom row containing 8 shot, and the second only 7; that is, the rows forming the progression 8, 7, 6, 5, 4, 3, 2, 1, in which each of the terms being the square root of the shot contained in each separate square course employed in forming the square pile; it follows, that the sum of the squares of these roots will be the shot required: and the sum of the squares divided by 8. 7. 6. 5. 4. 3. 2. 1, being 204, expresses the shot in the proposed pile.

## QUESTION X.

To find the shot of the oblong pile ABCDEF, fig. 3; in which BF = 16, and BC = 7.

## SOLUTION.

The oblong pile proposed, consisting of the square pile ABCD, whose bottom row is 7 shot; besides 9 arithmetical triangles or progressions, in which the first and last term, as also the number of terms, are known; it follows, that,

if to the contents of the square pile	-	140
we add the sum of the 9th progression	-	252
their total gives the contents required	-	392 shot.

## REMARK I.

The shot in the triangular and the square piles, as also the shot in each horizontal course, may at once be ascertained

tained by the following table: the vertical column A, contains the shot in the bottom row, from 1 to 20 inclusive; the column B contains the triangular numbers, or number of each course; the column C contains the sum of the triangular numbers, that is, the shot contained in a triangular pile, commonly called pyramidal numbers; the column D contains the square of the numbers of the column A, that is, the shot contained in each square horizontal course; and the column F contains the sum of these squares or shot in a square pile.

C	B	A	D	F
Pyramidal numbers.	Triangular numbers.	Natural numbers.	Square of the natural numbers.	Sum of these square numbers.
1	1	1	1	1
4	3	2	4	5
10	6	3	9	14
20	10	4	16	30
35	15	5	25	55
56	21	6	36	91
84	28	7	49	140
120	36	8	64	204
165	45	9	81	285
220	55	10	100	385
286	66	11	121	506
364	78	12	144	650
455	91	13	169	819
560	105	14	196	1015
680	120	15	225	1240
816	136	16	256	1496
969	153	17	289	1785
1140	171	18	324	2109
1330	190	19	361	2470
1540	210	20	400	2870

Thus, the bottom row in a triangular pile, consisting of 9 shot, the contents will be 165; and when of 9 in the square pile, 285.—In the same manner, the contents either of a square or triangular pile being given, the shot in the bottom row may be easily ascertained.

The contents of any oblong pile by the preceding table may be also with little trouble ascertained, the lesser side not exceeding 20 shot, nor the difference between the lesser and the greater side 20. Thus, to find the shot in an oblong pile,

the

the lesser side being 15, and the greater 35, we are first to find the contents of the square pile, by means of which the oblong pile may be conceived to be formed; that is, we are to find the contents of a square pile, whose bottom row is 15 shot; which being 1240, we are, secondly, to add these 1240 to the product 2400 of the triangular number 120, answering to 15, the number expressing the bottom row of the arithmetical triangle, multiplied by 20, the number of those triangles; and their sum, being 3640, expresses the number of shot in the proposed oblong pile.

## REMARK II.

The following algebraical expressions, deduced from the investigations of the sums of the powers of numbers in arithmetical progression, which are seen upon many gunners' callipers\*, serve to compute with ease and expedition the shot or shells in any pile.

That serving to compute any triangular pile, is represented by  $\left\{ \frac{n + 2 \times n + 1 \times n}{6} \right.$ .

That serving to compute any square pile, is represented by  $\left\{ \frac{n + 1 \times 2n + 1 \times n}{6} \right.$ .

In each of these, the letter  $n$  represents the number in the bottom row: hence, in a triangular pile, the number in the bottom row being 30; then this pile will be  $30 + 2 \times 30 + 1 \times \frac{3^2}{6} = 4960$  shot or shells. In a square pile, the number in the bottom row being also 30; then this pile will be  $30 + 1 \times 60 + 1 \times \frac{3^2}{6} = 9455$  shot or shells.

That serving to compute any oblong pile, is represented by  $\frac{2n + 1 + 3m \times n + 1 \times n}{6}$ , in which the letter  $n$  denotes

\* Callipers are large compasses, with bowed shanks, serving to take the diameters of convex and concave bodies. The gunners' callipers consist of two thin rules or plates, which are moveable quite round a joint, by the plates folding one over the other: the length of each rule or plate is six inches, the breadth about one inch. It is usual to represent, on the plates, a variety of scales, tables, proportions, &c, such as are esteemed useful to be known by persons employed about artillery; but, except the measuring of the caliber of shot and cannon, and the measuring of salient and re-entering angles, none of the articles, with which the callipers are usually filled, are essential to that instrument.

the number of courses, and the letter  $m$  the number of shot, less one, in the top row: hence, in an oblong pile the number of courses being 30, and the top row 31; this pile will be  $60 + 1 + 90 \times 30 + 1 \times \frac{30}{2} = 23405$  shot or shells.

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## GEOMETRICAL PROPORTION.

**GEOMETRICAL PROPORTION** is that relation of two quantities of the same kind, which arises from considering what part the one is of the other, or how often one contains another.

When two quantities are compared together, the first is called the Antecedent, and the second the Consequent.

Ratio is the quotient which arises from dividing the antecedent by the consequent, or the consequent by the antecedent.

Four Quantities are said to be proportional, when the first is the same part or multiple of the second, as the third is of the fourth.

Thus, 2, 8, 3, 12, and  $a, ar, b, br$ , are geometrical proportionals.

**Direct Proportion** is when the same relation subsists between the first term and the second, as between the third and the fourth.

Thus, 3, 6, 5, 10, and  $x, ax, y, ay$ , are in direct proportion.

**Reciprocal, or Inverse Proportion**, is when one quantity increases in the same proportion as another diminishes.

Thus, 2, 6, 9, 3, and  $a, ar, br, b$ , are in inverse proportion.

A Series of Quantities are said to be in geometrical progression, when the first has the same ratio to the second as the second to the third, and the third to the fourth, &c.

Thus, 2, 4, 8, 16, 32, 64, &c, and  $a, ar, ar^2, ar^3, ar^4, ar^5, \dots$ , are said to be in geometrical progression.

The most useful part of geometrical proportion, is contained in the following theorems :

1. If four quantities be in geometrical proportion, the product of the two extremes will be equal to the product of the two means.

Thus, if 2, 4, 6, 12, and  $a, ar, b, br$ , be geometrically proportional, then will  $2 \times 12 = 4 \times 6$ , and  $a \times br = b \times ar$ .

2. If four quantities be in geometrical proportion, the rectangle or product of the means divided by either of the extremes, will give the other extreme.

Thus, if 3, 9, 5, 15, and  $x, ax, y, ay$ , are geometrically proportional, then will  $\frac{9 \times 5}{3} = 15$ , and  $\frac{ax \times y}{ay} = x$ .

And this is the foundation of the Rule of Three.

3. In any continued geometrical progression, the product of the two extremes, and that of any other two terms, equally distant from them, will be equal to each other.

Thus, in the series 1, 3, 9, 27, 81, 243, &c,  
it is  $1 \times 243 = 3 \times 81 = 9 \times 27 = 243$ .

4. In any continued geometrical series, the last term is equal to the first multiplied by such a power of the ratio as is denoted by the number of terms less one.

Thus, in the series 2, 6, 18, 54, 162, &c;  $2 \times 3^4 = 162$ .

5. The sum of any series in geometrical progression, is found by multiplying the last term by the ratio, and dividing the difference of this product and the first term by the ratio less one.

Thus, the sum of 2, 4, 8, 16, 32, 64, 128, 256, 512, is  

$$\frac{512 \times 2 - 2}{2 - 1} = 1024 - 2 = 1022$$
.

And the sum of  $n$  terms of  $a, ar, ar^2, ar^3, ar^4, \dots$ , to  $ar^{n-1}$  is  $\frac{ar^{n-1} \times r - a}{r - 1} = \frac{ar^n - a}{r - 1} = \frac{r^n - 1}{r - 1} a$ .

6. If four quantities,  $a, b, c, d$ , or 2, 6, 5, 15, be proportional; then will any of the following forms of those quantities be also proportional, viz.

1. Directly,  $a : b :: c : d$     or  $2 : 6 :: 5 : 15$ .

2. Inversely,  $b : a :: d : c$     or  $6 : 2 :: 15 : 5$ .

3. Alternately,  $a : c :: b : d$     or  $2 : 6 :: 5 : 15$ .

4. Com-

4. Compoundedly,  $a : a + b :: c : c + d$ , or  $2 : 8 :: 5 : 20$ .
5. Dividedly,  $a : b - a :: c : d - c$ , or  $2 : 4 :: 5 : 10$ .
6. Mixed,  $b + a : b - a :: d + c : d - c$ , or  $8 : 4 :: 20 : 10$ .
7. Multiplication,  $ra : rb :: c : d$ , or  $2.3 : 6.3 :: 5 : 15$ .
8. Division,  $a \div r : b \div r :: c : d$  or  $1 : 3 :: 5 : 15$ .
9. The numbers  $a, b, c, d$ , are in harmonical proportion, when  $a : d :: a \infty b : c \infty d$ ; or when their reciprocals  $\frac{1}{a}, \frac{1}{b}, \frac{1}{c}, \frac{1}{d}$ , are in arithmetical proportion.

## EXAMPLES.

1. The first term of a geometrical series is 1, the ratio 2, and the number of terms 10; what is the sum of the series?

First,  $1 \times 2^9 = 1 \times 512$ , is the last term.

And,  $\frac{512 \times 2 - 1}{2 - 1} = \frac{1024 - 1}{1} = 1023$ , the sum required.

2. The first term of a geometric series is  $\frac{1}{2}$ , the ratio  $\frac{1}{3}$ , and the number of terms 5; required the sum of the series?

First,  $\frac{1}{2} \times (\frac{1}{3})^4 = \frac{1}{2} \times \frac{1}{81} = \frac{1}{162}$ , is the last term.

And,  $(\frac{1}{2} - \frac{1}{162} \times \frac{1}{3}) \div (1 - \frac{1}{3}) = (\frac{1}{2} - \frac{1}{486}) \div \frac{2}{3} = \frac{121}{243} \times \frac{3}{2} = \frac{121}{81} \times \frac{1}{2} = \frac{121}{162}$ , the sum required.

3. Required the sum of 1, 3, 9, 27, 81, &c. continued to 12 terms? Ans. 265720.

4. Required the sum of 1,  $\frac{1}{3}, \frac{1}{9}, \frac{1}{27}, \frac{1}{81}$ , &c. continued to 12 terms? Ans.  $\frac{265720}{177147}$ .

5. Required the sum of 1, 2, 4, 8, 16, 32, &c. continued to 100 terms? Ans. 1267650600228229401496703205375.

See more of Geometrical Proportion in the Arithmetic.

## SIMPLE EQUATIONS.

AN Equation, is when two equal quantities, differently expressed, are compared together by means of the sign = placed between them.

Thus,  $12 - 5 = 7$  is an equation, expressing the equality of the quantities  $12 - 5$  and 7.

A Simple

A Simple Equation, is that which contains only one power of the unknown quantity, without including different powers.

Thus,  $x - a + b = c$  is a simple equation, containing only one power of the unknown quantity  $x$ .

Reduction of Equations, is the method of finding the value of the unknown quantity.

It consists in ordering the equation so, that the unknown letter or quantity may stand alone on one side of the equation, or of the mark of equality, without a co-efficient; and all the rest, or the known quantities, on the other side.— In general, the unknown quantity is disengaged from the known ones, by performing the reverse operations. So, if they are connected with it by + or addition, they must be subtracted; if by minus (-), or subtraction, they must be added; if by multiplication, we must divide by them; if by division, we must multiply; also any power of the unknown quantity is taken away, by extracting the root; and any root is removed, by raising it to the power. As in the following rules; which are founded on the general principle of performing equal operations on equal quantities; in which case it is evident that the results must still be equal, whether by equal additions, or subtractions, or multiplications, or divisions, or roots, or powers.

#### RULE I.

WHEN known quantities are connected with the unknown by + or -; transpose them to the other side of the equation, and change their signs. Which is only adding or subtracting the same quantities on both sides.

Thus, if  $x + 3 = 7$ ; then will  $x = 7 - 3 = 4$ .

And, if  $x - 4 + 6 = 8$ ; then will  $x = 8 + 4 - 6 = 6$ .

Also, if  $x - a + b = c - d$ ; then will  $x = a - b + c - d$ .

And, in like manner, if  $4x - 8 = 3x + 20$ , then will  $4x - 3x = 20 + 8$ , or  $x = 28$ .

#### RULE II.

WHEN the unknown term is multiplied by any quantity; it is to be taken away by dividing all the terms of the equation by it.

Thus, if  $ax = ab - a$ ; then will  $x = b - 1$ .

And, if  $2x + 4 = 16$ ; then will  $x + 2 = 8$ , and  $x = 8 - 2 = 6$ .  
In

In like manner, if  $ax + 2ab = 3c^2$  ;  
then will  $x + 2b = \frac{3c^2}{a}$  and  $x = \frac{3c^2}{a} - 2b$ .

## RULE III.

WHEN the unknown term is divided by any quantity ; it may be taken away, by multiplying all the terms of the equation by it.

Thus, if  $\frac{x}{2} = 5 + 3$  ; then will  $x = 10 + 6 = 16$ .

And, if  $\frac{x}{a} = b + c - d$  ; then will  $x = ab + ac - ad$ .

In like manner, if  $\frac{2x}{3} - 2 = 6 + 4$  ; then will  $2x - 6 = 18 + 12$ , and  $2x = 18 + 12 + 6 = 36$ , or  $x = \frac{36}{2} = 18$ .

## RULE IV.

WHEN the unknown quantity is included in any furd ; transpose the rest of the terms, if there be any, by Rule 1, and then raise each side to such a power as is denoted by the index of the furd.

Thus, if  $\sqrt{x} - 2 = 6$  ; then will  $\sqrt{x} = 6 + 2 = 8$ , and  $x = 8^2 = 64$ .

And, if  $\sqrt[4]{4x + 16} = 12$ , then will  $4x + 16 = 144$ , or  $4x = 144 - 16 = 128$  ; and if both sides of the equation be divided by 4,  $x$  will be = 32.

In like manner, if  $\sqrt[3]{2x + 3} + 4 = 8$  ; then will  $\sqrt[3]{2x + 3} = 8 - 4 = 4$ , and  $2x + 3 = 4^3 = 64$ , and  $2x = 64 - 3 = 61$ , or  $x = \frac{61}{2} = 30\frac{1}{2}$ .

## RULE V.

IF that side of the equation which contains the unknown quantity be a complete power ; it may be reduced, by extracting the root of the said power on both sides of the equation.

Thus, if  $x^2 + 6x + 9 = 25$  ; then will  $x + 3 = \sqrt{25} = 5$ , or  $x = 5 - 3 = 2$ .

And if  $3x^2 - 19 = 21 + 35$  ; then will  $3x^2 = 21 + 35 + 19 = 75$ , and  $x^2 = \frac{75}{3} = 25$ , or  $x = \sqrt{25} = 5$ .

In like manner, if  $\frac{2x^2}{3} + 10 = 20$ ; then will  $2x^2 + 30 = 60$ , and  $x^2 + 15 = 30$ , or  $x^2 = 30 - 15 = 15$ , or  $x = \sqrt{15}$ .

## RULE VI.

ANY analogy or proportion may be changed into an equation, by making the product of the two extreme terms equal to that of the two means.

Thus, if  $3x : 16 :: 5 : 10$ ; then will  $3x \times 10 = 16 \times 5$ , that is,  $30x = 80$ , or  $x = \frac{80}{30} = \frac{8}{3} = 2\frac{2}{3}$ .

And, if  $\frac{2x}{3} : a :: b : c$ ; then will  $\frac{2cx}{3} = ab$ , and  $2cx = 3ab$ , or  $x = \frac{3ab}{2c}$ .

In like manner, if  $12 - x : \frac{x}{2} :: 4 : 1$ ; then will  $12 - x = \frac{4x}{2} = 2x$ , and  $2x + x = 12$ , or  $3x = 12$ , and  $x = \frac{12}{3} = 4$ .

## RULE VII.

IF the same quantity be found on both sides of an equation, with the same sign, either plus or minus, it may be taken away from each; and if every term in an equation be multiplied or divided by the same quantity, it may be struck out of them all.

Thus, if  $4x + a = b + a$ ; then will  $4x = b$ , and  $x = \frac{b}{4}$ .

And if  $3ax + 5ab = 8ac$ ; then will  $3x + 5b = 8c$ , and  $x = \frac{8c - 5b}{3}$ .

In like manner, if  $\frac{2x}{3} - \frac{8}{3} = \frac{16}{3} - \frac{8}{3}$ ; then will  $2x - 8 = 16 - 8$ , or  $2x = 16$ , and  $x = 8$ .

## MISCELLANEOUS EXAMPLES.

- Given  $5x - 15 = 2x + 6$ ; to find the value of  $x$ .

First,  $5x - 2x = 6 + 15$

Or,  $3x = 21$

Therefore  $x = \frac{21}{3} = 7$ .

2. Given

2. Given  $40 - 6x - 16 = 120 - 14x$ ; to find  $x$ .

First,  $14x - 6x = 120 - 40 + 16$ .

Or  $8x = 136 - 40 = 96$

Therefore  $x = \frac{96}{8} = 12$ .

3. Let  $5ax - 3b = 2dx + c$  be given; to find  $x$ .

First,  $5ax - 2dx = c + 3b$

Or  $(5a - 2d) \times x = c + 3b$

Therefore  $x = \frac{c + 3b}{5a - 2d}$ .

4. Let  $3x^2 - 10x = 8x + x^2$  be given; to find  $x$ .

First,  $3x - 10 = 8 + x$ , by dividing by  $x$

Then  $3x - x = 8 + 10 = 18$

And  $2x = 18$ , or  $x = \frac{18}{2} = 9$ .

5. Given  $6ax^3 - 12abx^2 = 3ax^3 + 6ax^2$ ; to find  $x$ .

First, dividing the whole by  $3ax^2$

we shall have  $2x - 4b = x + 2$

Or  $2x - x = 2 + 4b$

That is,  $x = 2 + 4b$ .

6. Let  $\frac{x}{2} - \frac{x}{3} + \frac{x}{4} = 10$  be given, to find  $x$ .

First,  $x - \frac{2x}{3} + \frac{2x}{4} = 20$

Also,  $3x - 2x + \frac{6x}{4} = 60$

And  $12x - 8x + 6x = 240$

Therefore  $10x = 240$

And  $x = \frac{240}{10} = 24$ .

7. Given  $\frac{x - 3}{2} + \frac{x}{3} = 20 - \frac{x - 19}{2}$ ; to find  $x$ .

First,  $x - 3 + \frac{2x}{3} = 40 - x + 19$

Also  $3x - 9 + 2x = 120 - 3x + 57$

Therefore,  $3x + 2x + 3x = 120 + 57 + 9$

That is,  $8x = 186$ , and  $x = \frac{186}{8} = 23\frac{1}{4}$

8. Let  $\sqrt{\frac{2x}{3}} + 5 = 7$ , be given; to find  $x$ .

$$\text{First } \sqrt{\frac{2x}{3}} = 7 - 5 = 2$$

$$\text{Then } \frac{2x}{3} = 2^2 = 4$$

$$\text{Hence } 2x = 12, \text{ or } x = \frac{12}{2} = 6.$$

9. Let  $x + \sqrt{a^2 + x^2} = \frac{2a^2}{\sqrt{a^2 + x^2}}$ , be given; to find  $x$ .

$$\text{First, } x\sqrt{a^2 + x^2} + a^2 + x^2 = 2a^2$$

$$\text{Then } x\sqrt{a^2 + x^2} = a^2 - x^2$$

$$\text{And } x^2 \times \frac{a^2 + x^2}{a^2 + x^2} = \frac{a^4 - x^4}{a^2 + x^2} = a^4 - 2a^2x^2 + x^4$$

$$\text{Hence } a^2x^2 + x^4 = a^4 - 2a^2x^2 + x^4$$

$$\text{Or } a^2x^2 + 2a^2x^2 = a^4, \text{ or } 3a^2x^2 = a^4$$

$$\text{Conseq. } x^2 = \frac{a^4}{3a^2} = \frac{a^2}{3}; \text{ and } x = \sqrt{\frac{a^2}{3}} = a\sqrt{\frac{1}{3}}.$$

### EXAMPLES FOR PRACTICE.

1. Given  $3x - 2 + 24 = 31$ ; to find  $x$ . Ans.  $x = 3$ .

2. Given  $x + 18 = 3x - 5$ ; to find  $x$ . Ans.  $x = 11\frac{1}{2}$ .

3. Given  $6 - 2x + 10 = 20 - 3x - 2$ ; to find  $x$ . Ans.  $x = 2$ .

4. Given  $x + \frac{1}{2}x + \frac{1}{3}x = 11$ ; to find  $x$ . Ans.  $x = 6$ .

5. Given  $2x - \frac{1}{2}x + 1 = 5x - 2$ ; to find  $x$ . Ans.  $x = \frac{6}{7}$ .

6. Given  $3ax + \frac{a}{2} - 3 = bx - a$ ; to find  $x$ .

$$\text{Ans. } x = \frac{6 - 3a}{6a - 2b}.$$

7. Given  $\frac{1}{2}x + \frac{1}{3}x - \frac{1}{4}x = \frac{1}{2}$ ; to find  $x$ . Ans.  $x = \frac{6}{7}$ .

8. Given  $\sqrt{12 + x} = 2 + \sqrt{x}$ ; to find  $x$ . Ans.  $x = 4$ .

9. Given  $a + x = \frac{x^2}{a + x}$ ; to determine  $x$ . Ans.  $x = -\frac{a}{2}$ .

10. Given  $\sqrt{a^2 + x^2} = \sqrt{b^2 + x^2}$ ; to find  $x$ .

$$\text{Ans. } x = \sqrt{\frac{b^4 - a^4}{2a^2}}.$$

11. Given  $\sqrt{x} + \sqrt{a + x} = \frac{2a}{\sqrt{a + x}}$ ; to find  $x$ .

$$\text{Ans. } x = \frac{a}{3}.$$

12. Given  $\frac{a}{1+x} + \frac{a}{1-x} = b$ ; to find  $x$ .

$$\text{Ans. } x = \sqrt{\frac{b - 2a}{b}}.$$

13. Given  $a + x = \sqrt{a^2 + x\sqrt{b^2 + x^2}}$ ; to find  $x$ .

$$\text{Ans. } x = \frac{b^2}{4a} - a.$$


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OF REDUCING DOUBLE, TRIPLE, &c, EQUATIONS, containing TWO, THREE, OR MORE UNKNOWN QUANTITIES.

#### PROBLEM I.

To Exterminate Two Unknown Quantities; Or, to Reduce the Two Simple Equations containing them, to a Single one.

#### RULE I.

1. FIND the value of one of the unknown letters, in terms of the other quantities, in each of the equations, by the methods already explained.

2. Let the two values, thus found, be made equal to each other, and there will arise a new equation with only one unknown quantity in it, whose value may be found as before.

*Note.* It is evident that we must first begin to find the values of that letter which are easiest to be found in the two proposed equations.

#### EXAMPLES.

1. Given  $\begin{cases} 2x + 3y = 23 \\ 5x - 2y = 10 \end{cases}$ ; to find  $x$  and  $y$ .

$$\text{From the first equation } x = \frac{23 - 3y}{2}$$

$$\text{And from the second } x = \frac{10 + 2y}{5}$$

$$\text{Consequently } \frac{23 - 3y}{2} = \frac{10 + 2y}{5}$$

$$\text{Theref. } 115 - 15y = 20 + 4y$$

$$\text{Hence } 19y = 115 - 20 = 95$$

$$\text{Then } y = \frac{95}{19} = 5$$

$$\text{And } x = \frac{23 - 15}{2} = 4.$$

2. Given

2. Given  $\begin{cases} x + y = a \\ x - y = b \end{cases}$ ; to find  $x$  and  $y$ .

From the first equation  $x = a - y$

And from the second  $x = b + y$

Therefore  $a - y = b + y$ , or  $2y = a - b$

Conseq.  $y = \frac{a - b}{2}$ , and  $x = a - y$

Or  $x = a - \frac{a - b}{2} = \frac{a + b}{2}$ .

3. Given  $\begin{cases} \frac{1}{2}x + \frac{1}{3}y = 7 \\ \frac{1}{3}x + \frac{1}{2}y = 8 \end{cases}$ ; to find  $x$  and  $y$ .

From the first equation  $x = 14 - \frac{2y}{3}$

And from the second  $x = 24 - \frac{3y}{2}$

Therefore  $14 - \frac{2y}{3} = 24 - \frac{3y}{2}$

Hence  $42 - 2y = 72 - \frac{9y}{2}$

Or  $84 - 4y = 144 - 9y$

Then  $5y = 144 - 84 = 60$

Therefore  $y = \frac{60}{5} = 12$

And  $x = 14 - \frac{2y}{3} = 14 - \frac{24}{3} = 6$ .

4. Given  $4x + y = 34$ , and  $4y + x = 16$ ; to find  $x$  and  $y$ .  
Ans.  $x = 8$ , and  $y = 2$ .

5. Given  $\frac{2x}{5} + \frac{3y}{4} = \frac{9}{20}$ , and  $\frac{3x}{4} + \frac{2y}{5} = \frac{61}{120}$ ; to find  $x$  and  $y$ .  
Ans.  $x = \frac{1}{2}$ , and  $y = \frac{1}{3}$ .

6. Given  $x + y = s$ , and  $x^2 - y^2 = d^2$ ; to find  $x$  and  $y$ .  
Ans.  $x = \frac{s^2 + d^2}{2s}$ , and  $y = \frac{s^2 - d^2}{2s}$ .

7. Given  $x - y = d$ , and  $x : y :: m : n$ ; to find  $x$  and  $y$ .

#### RULE II.

1. FIND the value of one of the unknown letters, in one only of the equations, as in the former rule.

2. Substitute the value, thus found, for that unknown quantity in the other equation, and there will arise a new

equation, with only one unknown quantity, whose value may be found as before.

## EXAMPLES.

1. Given  $\begin{cases} x + 2y = 17 \\ 3x - y = 2 \end{cases}$ ; to find  $x$  and  $y$ .

From the first equation  $x = 17 - 2y$

This value substituted for  $x$  in the second,

Gives  $(17 - 2y) \times 3 - y = 2$

Or,  $51 - 6y - y = 2$ , or  $51 - 7y = 2$

Then  $7y = 51 - 2 = 49$

Hence  $y = \frac{49}{7} = 7$ , and  $x = 17 - 2y = 17 - 14 = 3$ .

2. Given  $\begin{cases} x + y = 13 \\ x - y = 3 \end{cases}$ ; to find  $x$  and  $y$ .

From the first equation  $x = 13 - y$

This value being substituted for  $x$  in the 2d,

Gives  $13 - y - y = 3$ , or  $13 - 2y = 3$

Then  $2y = 13 - 3 = 10$

Hence  $y = \frac{10}{2} = 5$ , and  $x = 13 - y = 13 - 5 = 8$ .

3. Given  $\begin{cases} a : b :: x : y \\ x^2 + y^2 = c \end{cases}$ ; to find  $x$  and  $y$ .

The first analogy turned into an equation,

Gives  $bx = ay$ , or  $x = \frac{ay}{b}$

And this value of  $x$  being substituted in the 2d, gives

$$\left(\frac{ay}{b}\right)^2 + y^2 = c, \text{ or } \frac{a^2y^2}{b^2} + y^2 = c$$

Theref.  $a^2y^2 + b^2y^2 = b^2c$ , or  $y^2 = \frac{b^2c}{a^2 + b^2}$

Hence  $y = \sqrt{\frac{b^2c}{a^2 + b^2}}$ , and  $x = \sqrt{\frac{a^2c}{a^2 + b^2}}$

4. Given  $2x + 3y = 16$ , and  $3x - 2y = 11$ ; to find  $x$  and  $y$ .  
Ans.  $x = 5$ , and  $y = 2$ .

5. Given  $\frac{x}{7} + 7y = 99$ , and  $\frac{y}{7} + 7x = 51$ ; to find  $x$  and  $y$ .  
Ans.  $x = 7$ , and  $y = 14$ .

6. Given  $\frac{x}{2} - 12 = \frac{y}{4} + 8$ , and  $\frac{x+y}{5} + \frac{x}{3} - 8 = \frac{2y-x}{4} + 27$ ; to find  $x$  and  $y$ .  
Ans.  $x = 60$ , and  $y = 40$ .

7. Given

7. Given  $a : b :: x : y$ , and  $x^3 - y^3 = d^2$ ; to find  $x$  and  $y$ .

$$\text{Ans. } x = \sqrt[3]{\frac{ad^2}{a^3 - b}}, \text{ and } y = \sqrt[3]{\frac{bd^2}{a^3 - b}}.$$

## RULE III.

1. LET the given equations be multiplied, or divided, &c., by such numbers or quantities, as will make the term which contains one of the unknown quantities the same in both equations.

2. Then, by adding or subtracting the equations, according as the case may require, there will arise a new equation, with only one unknown quantity, as before.

## EXAMPLES.

1. Given  $\begin{cases} 3x + 5y = 40 \\ x + 2y = 14 \end{cases}$ ; to find  $x$  and  $y$ .

First, multiply the 2d equation by 3  
and it becomes  $3x + 6y = 42$

Then subtract the first from the last equation,  
and there remains  $6y - 5y = 42 - 40$ , or  $y = 2$   
Therefore  $x = 14 - 2y = 14 - 4 = 10$ .

2. Given  $\begin{cases} 5x - 3y = 9 \\ 2x + 5y = 16 \end{cases}$ ; to find  $x$  and  $y$ .

Let the first equation be multiplied by 2, and the 2d by 5,  
and we shall have  $10x - 6y = 18$   
and  $10x + 25y = 80$

Then if the former of these be subtracted from the latter,  
it will give  $31y = 62$ , or  $y = \frac{62}{31} = 2$

Conseq.  $x = \frac{9 + 3y}{5}$ , by the first equation

Or  $x = \frac{9 + 6}{5} = \frac{15}{5} = 3$ .

*Another Method.*

Multiply the first equation by 5, and the 2d by 3,

and we shall have  $\begin{cases} 25x - 15y = 45 \\ 6x + 15y = 48 \end{cases}$

Now, let these two equations be added together,

and the sum will be  $31x = 93$ , or  $x = \frac{93}{31} = 3$ .

Conseq.

Conseq.  $y = \frac{16 - 2x}{5}$ , by the second equation,

Or  $y = \frac{16 - 6}{5} = \frac{10}{5} = 2$ , as before.

### MISCELLANEOUS EXAMPLES.

1. Given  $\frac{x+2}{3} + 8y = 31$ , and  $\frac{y+5}{4} + 10x = 192$ ;  
to find  $x$  and  $y$ . Ans.  $x = 19$ , and  $y = 3$ .
2. Given  $\frac{2x-y}{2} + 14 = 18$ , and  $\frac{2y+x}{3} + 16 = 19$ ;  
to find  $x$  and  $y$ . Ans.  $x = 5$ , and  $y = 2$ .
3. Given  $\frac{2x+3y}{6} + \frac{x}{3} = 8$ , and  $\frac{7y-3x}{2} - y = 11$ ;  
to find  $x$  and  $y$ . Ans.  $x = 6$ , and  $y = 8$ .
4. Given  $ax + by = c$ , and  $dx + ey = f$ ; to find  $x$  and  $y$ .  
Ans.  $x = \frac{ce - bf}{ae - bd}$ , and  $y = \frac{af - dc}{ae - bd}$ .

### PROBLEM II.

*To Exterminate Three Unknown Quantities; Or, to Reduce the Three Simple Equations, containing them, to a Single one.*

#### R U L E.

1. AFTER the manner of the first rule in the last problem, find the value of one of the unknown letters in each of the given equations; next put two of these values equal to each other, and then one of these and the third value equal: which gives two new equations, with only two unknown quantities to be found as before.

2. Or, as in the 2d rule of the last problem; find the value of one of the unknown quantities in one of the equations; then substitute this value instead of it in the other two equations; which reduce to two only, to be resolved as before.

3. Or, as in the 3d rule of the last problem, reduce the equations, by multiplying or dividing them, so as to make some of the terms to agree: then, by adding or subtracting them, as the signs may require, one of the letters may be extermimated, &c, as before.

## EXAMPLES.

1. Given  $\begin{cases} x + y + z = 29 \\ x + 2y + 3z = 62 \\ \frac{1}{2}x + \frac{1}{3}y + \frac{1}{4}z = 10 \end{cases}$ ; to find  $x, y$ , and  $z$ .

From the first,  $x = 29 - y - z$

From the second,  $x = 62 - 2y - 3z$

From the third,  $x = 20 - \frac{2}{3}y - \frac{1}{2}z$

Then  $29 - y - z = 62 - 2y - 3z$

And  $29 - y - z = 20 - \frac{2}{3}y - \frac{1}{2}z$

Also from the first of these,  $y = 33 - 2z$

And from the second,  $y = 27 - \frac{3}{2}z$

Theref.  $33 - 2z = 27 - \frac{3}{2}z$ , or  $z = 12$

Hence also  $y = 33 - 2z = 9$

And  $x = 29 - y - z = 8$ .

2. Given  $\begin{cases} \frac{1}{2}x + \frac{1}{3}y + \frac{1}{4}z = 62 \\ \frac{1}{3}x + \frac{1}{4}y + \frac{1}{5}z = 47 \\ \frac{1}{4}x + \frac{1}{5}y + \frac{1}{6}z = 38 \end{cases}$ ; to find  $x, y$ , and  $z$ .

First, the given equations, cleared of fractions, become

$$12x + 8y + 6z = 1488$$

$$20x + 15y + 12z = 2820$$

$$30x + 24y + 20z = 4560$$

Then, if the second of these equations be subtracted from double the first, and 3 times the third from 5 times the second, we shall have

$$4x + y = 156$$

$$10x + 3y = 420$$

And again, if the second of these be subtracted from 3 times the first, it will give

$$12x - 10x = 468 - 420, \text{ or } x = \frac{48}{2} = 24.$$

Theref.  $y = 156 - 4x = 60$ , and  $z = \frac{1488 - 8y - 12x}{6} = 120$ .

3. Given  $x + y + z = 53$ , and  $x + 2y + 3z = 105$ , and  $x + 3y + 4z = 134$ ; to find  $x, y$ , and  $z$ .

Ansf.  $x = 24, y = 6$ , and  $z = 23$ .

4. Given  $x + y = a$ ,  $x + z = b$ , and  $y + z = c$ ; to find  $x, y$ , and  $z$ .

5. Given  $\begin{cases} ax + by + cz = m \\ dx + ey + fz = n \\ gx + hy + kz = p \end{cases}$ ; to find  $x, y$ , and  $z$ .

A COLLECTION OF QUESTIONS PRODUCING  
SIMPLE EQUATIONS.

1. To find two numbers, such, that their sum shall be 40, and their difference 16.

Let  $x$  denote the least of the two numbers required,

Then will  $x + 16 =$  to the greater,

And  $x + x + 16 = 40$  by the question,

That is,  $2x = 40 - 16 = 24$

Or  $x = \frac{24}{2} = 12$ , the least number required.

And  $x + 16 = 12 + 16 = 28$ , the greater number.

2. What number is that, whose  $\frac{1}{3}$  part exceeds its  $\frac{1}{4}$  part by 16?

Let  $x =$  number required,

Then will its  $\frac{1}{3}$  part be  $\frac{1}{3}x$ , and its  $\frac{1}{4}$  part  $\frac{1}{4}x$ ;

Therefore  $\frac{1}{3}x - \frac{1}{4}x = 16$  by the question,

Then is,  $x - \frac{3}{4}x = 48$ , or  $4x - 3x = 192$ ;

Hence  $x = 192$ , the number required.

3. Divide 1000*l.* among A, B, and C, so that A shall have 72*l.* more than B, and C 100*l.* more than A.

Let  $x =$  B's share of the given sum,

Then will  $x + 72 =$  A's share,

And  $x + 172 =$  C's share,

The sum of all their shares is  $x + x + 72 + x + 172$ ,

Or  $3x + 244 = 1000$  by the question,

That is,  $3x = 1000 - 244 = 756$ ,

Then  $x = \frac{756}{3} = 252l.$  = B's share;

Hence  $x + 72 = 252 + 72 = 324l.$  = A's share,

And  $x + 172 = 252 + 172 = 424l.$  = C's share,

B's share,      252*l.*

A's share,      324*l.*

C's share,      424*l.*

Sum of all,      1000*l.* the proof.

4. A prize of 1000*l.* is to be divided between two persons, whose shares of it are in the proportion of 7 to 9; required the share of each.

Let  $x$  = first person's share,

Then will  $1000 - x$  = second person's share,

And  $x : 1000 - x :: 7 : 9$ , by the question,

The

Then  $9x = (1000 - x) \times 7 = 7000 - 7x$ ,

Or  $9x + 7x = 16x = 7000$ ,

Hence  $x = \frac{7000}{16} = 437l. 10s. = 1st \text{ share}$ ,

And  $1000 - x = 1000 - 437l. 10s. = 562l. 10s., 2d \text{ share.}$

5. The paving of a square at 2s. a yard, cost as much as the inclosing it at 5s. a yard: required the side of the square?

Let  $x = \text{side of the square fought}$ ,

Then  $4x = \text{yards of inclosure}$ ,

And  $x^2 = \text{yards of pavement}$ ;

Hence  $4x \times 5 = 20x = \text{price of inclosing}$ ,

And  $x^2 \times 2 = 2x^2 = \text{price of paving}$ ,

But  $2x^2 = 20x$  by the question,

Theref.  $2x = 20$ , and  $x = 10$  the length of the side required.

6. A labourer engaged to serve for 40 days on these conditions: that for every day he worked, he was to receive 20d. but for every day he played, or was absent, he was to forfeit 8d. Now at the end of the time he had to receive 1l. 11s. 8d. It is required to find how many days he worked, and how many he was idle?

Let  $x$  be the number of days he worked,

Then will  $40 - x$  be the number of days he was idle,

Also  $x \times 20 = 20x = \text{the sum earned}$ ,

And  $(40 - x) \times 8 = 320 - 8x = \text{sum forfeited}$ ,

Hence  $20x - (320 - 8x) = 380d. = (1l. 11s. 8d.)$

by the question; that is,  $20x - 320 + 8x = 380$ ,

Or  $28x = 380 + 320 = 700$ ,

Hence  $x = \frac{700}{28} = 25$  the number of days he worked,

And  $40 - x = 40 - 25 = 15$  the number of days he was idle.

7. Out of a cask of wine, which had leaked away  $\frac{1}{3}$ , 21 gallons were drawn; and then, being gauged, it appeared to be half full; how much did it hold?

Let it be supposed to have held  $x$  gallons,

Then it would have leaked  $\frac{1}{3}x$  gallons,

Conseq. there had been taken away  $21 + \frac{1}{3}x$  gallons.

But  $21 + \frac{1}{3}x = \frac{1}{2}x$  by the question

Theref.  $63 + x = \frac{3}{2}x$

Or  $126 + 2x = 3x$

Hence  $3x - 2x = 126$

Or  $x = 126$ , the number of gallons required.

8. What fraction is that, to the numerator of which, if 1 be added, the value will be  $\frac{1}{3}$ ; but if 1 be added to the denominator, its value will be  $\frac{1}{4}$ .

Let the fraction be represented by  $\frac{x}{y}$

$$\text{Then will } \frac{x+1}{y} = \frac{1}{3}$$

$$\text{And } \frac{x}{y+1} = \frac{1}{4}$$

$$\text{Hence } 3x + 3 = y$$

$$\text{And } 4x = y + 1$$

$$\text{Theref. } 4x - 3x - 3 = y + 1 - y$$

$$\text{That is } x - 3 = 1, \text{ or } x = 4.$$

$$\text{Hence } y = 3x + 3 = 12 + 3 = 15.$$

So that  $\frac{4}{15}$  is the fraction required.

9. A market woman bought in a certain number of eggs at 2 a penny, and as many more at 3 a penny, and sold them all out again at the rate of 5 for two-pence, and by so doing lost 4d.: what number of eggs had she?

Let  $x$  = number of eggs of each sort,

Then will  $\frac{1}{2}x$  = price of the first sort,

And  $\frac{1}{3}x$  = price of the second sort;

But  $5 : 2 :: 2x$  (the whole number of eggs) :  $\frac{4}{5}x$ ;

Whence  $\frac{4}{5}x$  = price of both sorts, at 5 for 2 pence,

And  $\frac{1}{2}x + \frac{1}{3}x - \frac{4}{5}x = 4$  by the question;

Theref.  $x + \frac{2}{3}x - \frac{8}{5}x = 8$ ,

Or  $3x + 2x - \frac{24}{5}x = 24$ ;

Or  $15x + 10x - 24x = 120$ ,

Or  $x = 120$ , the number of eggs of each sort.

10. If A can do a piece of work alone in 10 days, and B in 13; set them both about it together, in what time will it be finished?

Let the time sought be denoted by  $x$ .

Then 10 days : 1 work ::  $x$  days :  $\frac{1}{10}x$ .

And 13 days : 1 work ::  $x$  days :  $\frac{1}{13}x$ :

Hence  $\frac{1}{10}x$  = part done by A in  $x$  days,

And  $\frac{1}{13}x$  = part done by B in  $x$  days;

Consequently  $\frac{1}{10}x + \frac{1}{13}x = 1$ ;

That is  $\frac{13}{130}x + x = 13$ , or  $13x + 10x = 130$ ;

Hence  $23x = 130$ , and  $x = \frac{130}{23} = 5\frac{5}{23}$  days, the time required.

11. If one agent A, alone, can produce an effect  $e$ , in the time  $a$ ; and another agent B, alone, in the time  $b$ ; in what time will they both together produce the same effect?

Let the time sought be denoted by  $x$ .

Then  $a : e :: x : \frac{ex}{a}$  = part of the effect produced by A,

And  $b : e :: x : \frac{ex}{b}$  = part of the effect produced by B,

Hence  $\frac{ex}{a} + \frac{ex}{b} = e$  by the question;

Or  $\frac{x}{a} + \frac{x}{b} = 1$ ;

Theref.  $x + \frac{ax}{b} = a$ ;

And  $bx + ax = ab$ ;

Conseq.  $x = \frac{ab}{a+b}$  = time required.

#### QUESTIONS FOR PRACTICE.

1. WHAT two numbers are those whose difference is 7, and sum 33? Anf. 13 and 20.

2. To divide the number 75 into two such parts, that 3 times the greater may exceed 7 times the less by 15. Anf. 54 and 21.

3. In a mixture of wine and cyder,  $\frac{1}{2}$  of the whole plus 25 gallons was wine, and  $\frac{1}{3}$  part minus 5 gallons was cyder: how many gallons were there of each?

Anf. 85 of wine, and 35 of cyder.

4. A bill of 120*l.* was paid in guineas and 27-shilling pieces, and the number of pieces of both sorts that were used was just 100; how many were there of each?

Anf. 50 of each.

5. Two travellers set out at the same time from London and York, the distance between them being 198 miles; one of them goes 8 miles a day, and the other 7; in what time will they meet? Anf. in  $13\frac{1}{3}$  days.

6. At a certain election 375 persons voted for two candidates, and the candidate chosen had a majority of 91; how many voted for each?

Anf. 233 for one, and 142 for the other.

7. What number is that from which, if 5 be subtracted,  $\frac{2}{3}$  of the remainder will be 40? Anf. 65.

8. A

8. A post is  $\frac{1}{4}$  in the mud,  $\frac{1}{3}$  in the water, and 10 feet above the water; what is the whole length? Anf. 24 feet.

9. There is a fish whose tail weighs 9lb. his head weighs as much as his tail and half his body, and his body weighs as much as his head and tail; what is the whole weight of the fish? Anf. 72lb.

10. After paying away  $\frac{1}{4}$  and  $\frac{1}{5}$  of my money, I had 66 guineas left in my purse; what was in it at first?

Anf. 120 guineas.

11. A's age is double of B's, and B's is triple of C's, and the sum of all their ages is 140; what is the age of each?

Anf. A's = 84, B's = 42, and C's = 14.

12. Two persons, A and B, lay out equal sums of money in trade; A gains 12*l.* and B loses 8*l.* and A's money is now double of B's; what did each lay out? Anf. 300*l.*

13. A person bought a chaise, horse, and harness, for 60*l.* the horse came to twice the price of the harness, and the chaise to twice the price of the horse and harness: what did he give for each?

Anf. 13*l.* 6*s.* 8*d.* for the horse, 6*l.* 13*s.* 4*d.* for the harness, and 40*l.* for the chaise.

14. Two persons, A and B, have both the same income; A saves  $\frac{1}{3}$  of his yearly, but B, by spending 50*l.* per annum more than A, at the end of 4 years finds himself 100*l.* in debt; what is their income? Anf. 125*l.*

15. A person has two horses, and a saddle worth 50*l.*: now if the saddle be put on the back of the first horse, it will make his value double that of the second; but if it be put on the back of the second, it will make his value triple that of the first; what is the value of each horse?

Anf. One 30*l.* and the other 40*l.*

16. To divide the number 36 into three such parts, that  $\frac{1}{2}$  of the first,  $\frac{1}{3}$  of the second, and  $\frac{1}{4}$  of the third, may be all equal to each other? Anf. The parts are 8, 12, and 16.

17. A footman agreed to serve his master for 24*l.* a year and a livery; but was turned away at the end of 7 months, and received only 8*l.* and his livery; what was its value?

Anf. 14*l.* 8*s.*

18. A person was desirous of giving 3*d.* a-piece to some beggars, but found that he had not money enough in his pocket by 8*d.*; he therefore gave them each 2*d.*, and had then 3*d.* remaining; required the number of beggars?

Anf. 11.

19. A

19. A hare is 50 leaps before a greyhound, and takes 4 leaps to the greyhound's 3; but two of the greyhound's leaps are as much as three of the hare's: how many leaps must the greyhound take to catch the hare? Anf. 300.

20. A person in play lost  $\frac{1}{4}$  of his money, and then won 3 guineas; after which he lost  $\frac{1}{3}$  of what he then had, and then won 2 guineas; lastly he lost  $\frac{1}{7}$  of what he then had; and, this done, found he had but 12 guineas remaining; what had he at first? Anf. 20 guineas.

21. To divide the number 90 into 4 such parts, that if the first be increased by 2, the second diminished by 2, the third multiplied by 2, and the fourth divided by 2; the sum, difference, product, and quotient shall be all equal to each other.

Anf. The parts are 18, 22, 10, and 40, respectively.

22. The hour and minute hands of a clock are exactly together at 12 o'clock: when are they next together?

Anf. 1 hour  $5\frac{5}{11}$  minutes.

23. There is an island 73 miles in circumference, and three footmen all start together to travel the same way about it: A goes 5 miles a day, B 8, and C 10: when will they all come together again? Anf. In 73 days.

24. How much foreign brandy at 16s. per gallon, and British spirits at 6s. per gallon, must be mixed together, so that in selling the compound at 18s. per gallon, the distiller may clear 30 per cent.?

Anf. 51 gallons of brandy, and 14 of spirits.

25. A man and his wife usually drank out a cask of beer in 12 days; but when the man was from home, it lasted the woman 30 days; how many days would the man alone be in drinking it? Anf. 20 days.

26. If A and B together can perform a piece of work in 8 days; A and C together in 9 days; and B and C in 10 days; how many days will it take each person to perform the same work alone?

Anf. A  $14\frac{4}{47}$  days, B  $17\frac{2}{47}$ , and C  $23\frac{7}{47}$ .

27. If three agents, A, B, and C, can produce the effects  $a$ ,  $b$ ,  $c$ , in the times  $e$ ,  $f$ ,  $g$ , respectively; in what time would they jointly produce the effect  $d$ ?

Anf.  $d \div (\frac{a}{e} + \frac{b}{f} + \frac{c}{g})$  time.

## QUADRATIC EQUATIONS.

A SIMPLE Quadratic Equation, is that which involves the square of the unknown quantity only.

A compound Quadratic Equation, is that which contains the square of the unknown quantity in one term, and the first power in another term.

Thus  $ax^2 = b$ , is a simple quadratic equation;

And  $ax^2 + bx = c$ , is a compound quadratic equation.

The rule for a simple quadratic equation has been given already.

All compound quadratic equations, after being properly reduced, fall under the three following forms :

1.  $x^2 + ax = b$
2.  $x^2 - ax = b$
3.  $x^2 - ax = -b$

The rule for finding the value of  $x$ , in all quadratic equations, is as follows :

1. REDUCE the proposed equation to a proper simple form, as usual, namely by transposing all the terms which contain the unknown quantity to one side of the equation, and the known terms to the other, and by ranging them according to their dimensions, as in the forms above.

2. When the first term or square of the unknown quantity has any co-efficient prefixed to it, free it from that co-efficient in the usual way, viz. by dividing all the terms by that co-efficient; which will bring the equation to one of the three forms above.

3. Then complete the unknown side to a square in this manner, viz. Take half the co-efficient of the second term and square it, which square add to both sides of the equation; then that side which contains the unknown quantity will be a complete square.

4. Extract the square root on both sides of the equation \*, and the value of the unknown quantity will be determined, as was required, making the root of the known side either + or -, which will give two roots of the equation, or two values of the unknown quantity.

*Note,*

\* The square root of any quantity may be either + or -, and therefore all quadratic equations admit of two solutions. Thus the square root of  $+n^2$  is either  $+n$  or  $-n$ ; for  $+n \times +n$  and  $-n \times -n$  are each equal to  $+n^2$ . But the square root of  $-n^2$ , or  $\sqrt{-n^2}$ , is imaginary or impossible, as neither  $+n$  nor  $-n$ , when squared, give  $-n^2$ .

So, in the first form,  $x^2 + ax = b$ , where  $x + \frac{1}{2}a$  is found =  $\sqrt{b + \frac{1}{4}a^2}$ , the root may be either  $+\sqrt{b + \frac{1}{4}a^2}$ , or  $-\sqrt{b + \frac{1}{4}a^2}$ , since either of them being multiplied by itself will produce  $b + \frac{1}{4}a^2$ . And this ambiguity is expressed by writing the uncertain or double sign  $\pm$  before  $\sqrt{b + \frac{1}{4}a^2}$ ; thus  $x = \pm\sqrt{b + \frac{1}{4}a^2} - \frac{1}{2}a$ .

In this form, where  $x = \pm\sqrt{b + \frac{1}{4}a^2} - \frac{1}{2}a$ , the first value of  $x$ , viz.  $x = +\sqrt{b + \frac{1}{4}a^2} - \frac{1}{2}a$ , is always affirmative; for since  $\frac{1}{4}a^2 + b$  is greater than  $\frac{1}{4}a^2$ , the greatest square must necessarily have the greatest square root; therefore  $\sqrt{b + \frac{1}{4}a^2}$  will always be greater than  $\sqrt{\frac{1}{4}a^2}$ , or its equal  $\frac{1}{2}a$ ; and consequently  $+\sqrt{b + \frac{1}{4}a^2} - \frac{1}{2}a$  will always be affirmative.

The second value, viz.  $x = -\sqrt{b + \frac{1}{4}a^2} - \frac{1}{2}a$  will always be negative, because it is composed of two negative terms. Therefore when  $x^2 + ax = b$ , we shall have  $x = +\sqrt{b + \frac{1}{4}a^2} - \frac{1}{2}a$  for the affirmative value of  $x$ , and  $x = -\sqrt{b + \frac{1}{4}a^2} - \frac{1}{2}a$  for the negative value of  $x$ .

In the second form, where  $x = \pm\sqrt{b + \frac{1}{4}a^2} + \frac{1}{2}a$  the first value, viz.  $x = +\sqrt{b + \frac{1}{4}a^2} + \frac{1}{2}a$  is always affirmative, since it is composed of two affirmative terms. The second value, viz.  $x = -\sqrt{b + \frac{1}{4}a^2} + \frac{1}{2}a$ , will always be negative; for since  $b + \frac{1}{4}a^2$  is greater than  $\frac{1}{4}a^2$ ,  $\sqrt{b + \frac{1}{4}a^2}$  will be greater than  $\sqrt{\frac{1}{4}a^2}$ , or its equal  $\frac{1}{2}a$ ; and consequently  $-\sqrt{b + \frac{1}{4}a^2} + \frac{1}{2}a$  is always a negative quantity.

Therefore, when  $x^2 - ax = b$ , we shall have  $x = +\sqrt{b + \frac{1}{4}a^2} + \frac{1}{2}a$  for the affirmative value of  $x$ , and  $x = -\sqrt{b + \frac{1}{4}a^2} + \frac{1}{2}a$  for the negative value of  $x$ ; so that in both the first and second forms, the unknown quantity has always two values, one of which is positive, and the other negative.

*Note*, 1. The root of the first side of the equation, is always equal to the unknown quantity, with half the coefficient of the second term subjoined to it, with its proper sign.

2. All equations, in which there are two terms including the unknown quantity, and which have the index of the one just double that of the other, are resolved like quadratics, by completing the square; as above.

Thus,  $x^4 + ax^2 = b$ , or  $x^{2n} + ax^n = b$ , or  $x + ax^{\frac{1}{2}} = b$ , are the same as quadratics, and the value of the unknown quantity may be determined accordingly.

#### EXAMPLES.

1. Given  $x^2 + 4x = 140$ ; to find  $x$ .

First,  $x^2 + 4x + 4 = 140 + 4 = 144$ , by completing the square.

Then  $\sqrt{x^2 + 4x + 4} = \sqrt{144}$ , by extracting the roots;

Or, which is the same thing,  $x + 2 = \pm 12$ .

Theref.  $x = \pm 12 - 2 = 10$  or  $-14$ , the two roots.

In the third form, where  $x = \pm \sqrt{\frac{1}{4}a^2 - b} + \frac{1}{2}a$ , both the values of  $x$  will be positive, supposing  $\frac{1}{4}a^2$  is greater than  $b$ . For the first value, viz.  $x = + \sqrt{\frac{1}{4}a^2 - b} + \frac{1}{2}a$  will then be affirmative, being composed of two affirmative terms.

The second value, viz.  $x = - \sqrt{\frac{1}{4}a^2 - b} + \frac{1}{2}a$  is affirmative also; for since  $\frac{1}{4}a^2$  is greater than  $\frac{1}{4}a^2 - b$ ,  $\sqrt{\frac{1}{4}a^2}$  or  $\frac{1}{2}a$  is greater than  $\sqrt{\frac{1}{4}a^2 - b}$ ; and consequently  $- \sqrt{\frac{1}{4}a^2 - b} + \frac{1}{2}a$  will always be an affirmative quantity. Therefore, when  $x^2 - ax = -b$ , we shall have  $x = + \sqrt{\frac{1}{4}a^2 - b} + \frac{1}{2}a$ , and also  $x = - \sqrt{\frac{1}{4}a^2 - b} + \frac{1}{2}a$  for the values of  $x$ , both affirmative.

But in this third form, if  $b$  be greater than  $\frac{1}{4}a^2$ , the solution of the proposed question will be impossible. For since the square of any quantity (whether that quantity be affirmative or negative) is always affirmative, the square root of a negative quantity is impossible, and cannot be assigned. But if  $b$  be greater than  $\frac{1}{4}a^2$ , then  $\frac{1}{4}a^2 - b$  is a negative quantity; and therefore  $\sqrt{\frac{1}{4}a^2 - b}$  is impossible, or imaginary; consequently, in that case,  $x = \frac{1}{2}a \pm \sqrt{\frac{1}{4}a^2 - b}$ , or the two roots or values of  $x$ , are both impossible, or imaginary quantities.

2. Given

2. Given  $x^2 - 6x + 8 = 80$ ; to find  $x$ .

First,  $x^2 - 6x = 80 - 8 = 72$ , by transposition;  
 Then  $x^2 - 6x + 9 = 72 + 9 = 81$ , by completing the sq.  
 And  $x - 3 = \sqrt{81} = \pm 9$ , by extracting the root;  
 Theref.  $x = \pm 9 + 3 = 12$  or  $-6$ .

3. Given  $2x^2 + 8x - 20 = 70$ ; to find  $x$ .

First,  $2x^2 + 8x = 70 + 20 = 90$  by transposition;  
 Then  $x^2 + 4x = 45$  by dividing by 2;  
 And  $x^2 + 4x + 4 = 49$  by completing the square;  
 Hence  $x + 2 = \sqrt{49} = \pm 7$  by extracting the root;  
 Consequently  $x = \pm 7 - 2 = 5$  or  $-9$ .

4. Given  $3x^2 - 3x + 6 = 5\frac{1}{3}$ ; to find  $x$ .

Here  $x^2 - x + 2 = 1\frac{7}{9}$  by dividing by 3,  
 And  $x^2 - x = 1\frac{7}{9} - 2$  by transposition:  
 Also  $x^2 - x + \frac{1}{4} = 1\frac{7}{9} - 2 + \frac{1}{4} = \frac{1}{36}$  by compl. the sq.  
 Hence  $x - \frac{1}{2} = \sqrt{\frac{1}{36}} = \pm \frac{1}{6}$  by evolution;  
 Therefore  $x = \pm \frac{1}{6} + \frac{1}{2} = \frac{2}{3}$  or  $\frac{1}{3}$ .

5. Given  $\frac{1}{2}x^2 - \frac{1}{3}x + 20\frac{1}{2} = 42\frac{2}{3}$ ; to find  $x$ .

Here,  $\frac{1}{2}x^2 - \frac{1}{3}x = 42\frac{2}{3} - 20\frac{1}{2} = 22\frac{1}{6}$  by transposition;  
 And  $x^2 - \frac{2}{3}x = 44\frac{1}{3}$  by multiplying by 2.  
 Then  $x^2 - \frac{2}{3}x + \frac{1}{9} = 44\frac{1}{3} + \frac{1}{9} = 44\frac{4}{9}$  by compl. sq.  
 Hence  $x - \frac{1}{3} = \sqrt{44\frac{4}{9}} = \pm \frac{6\frac{2}{3}}{3}$  by evolution;  
 Therefore  $x = \pm \frac{6\frac{2}{3}}{3} + \frac{1}{3} = 7$  or  $-6\frac{1}{3}$ .

6. Given  $ax^2 + bx = c$ ; to find  $x$ .

First,  $x^2 + \frac{b}{a}x = \frac{c}{a}$  by division;

Then  $x^2 + \frac{b}{a}x + \frac{b^2}{4a^2} = \frac{c}{a} + \frac{b^2}{4a^2}$  by compl. square.

And  $x + \frac{b}{2a} = \sqrt{\left(\frac{c}{a} + \frac{b^2}{4a^2}\right)} = \pm \sqrt{\frac{4ac + b^2}{4a^2}}$  by evolut.

Theref.  $x = \pm \sqrt{\frac{4ac + b^2}{4a^2}} - \frac{b}{2a} = \frac{\pm \sqrt{4ac + b^2} - b}{2a}$ .

7. Given  $ax^2 - bx + c = d$ ; to find  $x$ .

Here,  $ax^2 - bx = d - c$  by transposition;

And  $x^2 - \frac{b}{a}x = \frac{d - c}{a}$  by division;

Also  $x^2 - \frac{b}{a}x + \frac{b^2}{4a^2} = \frac{d-c}{a} + \frac{b^2}{4a^2}$  by compl. the sq.

Hence  $x - \frac{b}{2a} = \pm \sqrt{\left(\frac{d-c}{a} + \frac{b^2}{4a^2}\right)}$  by evolution;

Therefore  $x = \frac{b}{2a} \pm \sqrt{\left(\frac{d-c}{a} + \frac{b^2}{4a^2}\right)}.$

8. Given  $x^4 + 2ax^2 = b$ ; to find  $x$ .

Here,  $x^4 + 2ax^2 + a^2 = b + a^2$  by compl. the sq.

And  $x^2 + a = \pm \sqrt{b + a^2}$  by evolution;

Hence  $x^2 = \pm \sqrt{b + a^2} - a$ , by transposition;

And consequently  $x = \pm \sqrt{-a \pm \sqrt{b + a^2}}.$

9. Given  $ax^n - bx^{\frac{n}{2}} - c = -d$ : to find  $x$ .

First,  $ax^n - bx^{\frac{n}{2}} = c - d$  by transposition;

And  $x^n - \frac{b}{a}x^{\frac{n}{2}} = \frac{c-d}{a}$  by division;

Also  $x^n - \frac{b}{a}x^{\frac{n}{2}} + \frac{b^2}{4a^2} = \frac{c-d}{a} + \frac{b^2}{4a^2}$  by compl. the sq.

Hence  $x^{\frac{n}{2}} - \frac{b}{2a} = \pm \sqrt{\left(\frac{c-d}{a} + \frac{b^2}{4a^2}\right)}$  by evolution;

Therefore  $x^{\frac{n}{2}} = \frac{b}{2a} \pm \sqrt{\left(\frac{c-d}{a} + \frac{b^2}{4a^2}\right)},$

And conseq.  $x = \left(\frac{b}{2a} \pm \sqrt{\frac{4ac - 4ad + b^2}{4a^2}}\right)^{\frac{2}{n}}$ .

#### EXAMPLES FOR PRACTICE.

1. Given  $x^2 - 8x + 10 = 19$ ; to find  $x$ . Anf.  $x = 9$ .
2. Given  $x^2 - x - 40 = 170$ ; to find  $x$ . Anf.  $x = 15$ .
3. Given  $3x^2 + 2x - 9 = 76$ ; to find  $x$ . Anf.  $x = 5$ .
4. Given  $\frac{1}{2}x^2 - \frac{1}{3}x + 7\frac{3}{8} = 8$ ; to find  $x$ . Anf.  $x = 1\frac{1}{2}$ .
5. Given  $2x^3 - x^2 = 496$ ; to find  $x$ . Anf.  $x = 4$ .
6. Given  $\frac{1}{2}x - \frac{1}{2}\sqrt{x} = 22\frac{1}{6}$ ; to find  $x$ . Anf.  $x = 49$ .
7. Given  $\frac{2}{3}x^2 + \frac{3}{4}x = \frac{4}{5}$ ; to find  $x$ . Anf.  $x = .8179$ .
8. Given  $x^6 + 6x^3 = 2$ ; to find  $x$ . Anf.  $x = \sqrt[3]{-3 \pm \sqrt{11}}$ .
9. Given  $x^2 + x = a$ ; to find  $x$ . Anf.  $x = \sqrt{a + \frac{1}{4}} - \frac{1}{2}$ .
10. Given

10. Given  $x - \sqrt{x} = a$ ; to find  $x$ . Ans.  $x = (\frac{1}{2} \pm \sqrt{a + \frac{1}{4}})^2$ .
11. Given  $3x^2 - 2x^a = 25$ ; to find  $x$ .

$$\text{Ans. } x = (\frac{1}{3} \sqrt{76 + \frac{1}{3}})^{\frac{1}{2}}$$

12. Given  $\sqrt{1+x} - 2\sqrt[4]{1+x} = 4$ ; to find  $x$ .

$$\text{Ans. } x = (1 + \sqrt{5})^4 - 1.$$

### QUESTIONS PRODUCING QUADRATIC EQUATIONS.

1. To find two numbers whose difference is 8, and product 240.

Let  $x =$  to the least number.

Then will  $x + 8 =$  to the greater,

And  $x \times (x + 8) = x^2 + 8x = 240$  by the question;  
Thence  $x^2 + 8x + 16 = 240 + 16 = 256$  by completing the square;

And hence  $x + 4 = \sqrt{256} = 16$  by evolution;

Theref.  $x = 16 - 4 = 12$  the less number,

And  $12 + 8 = 20$  the greater.

2. To divide the number 60 into two such parts, that their product may be 864.

Let  $x =$  the one part,

Then will  $60 - x =$  the other,

And  $x \times (60 - x) = 60x - x^2 = 864$  by the question;  
That is  $x^2 - 60x = -864$ ;

Then  $x^2 - 60x + 900 = -864 + 900 = 36$  by completing the square;

Hence  $x - 30 = \pm \sqrt{36} = \pm 6$  by extracting the root;

Theref.  $x = 30 \pm 6 = 36$  or 24, the two parts.

3. Given the sum of two numbers = 10 ( $a$ ), and the sum of their squares = 58 ( $b$ ); to find those numbers.

Let  $x =$  the one number,

Then will  $a - x =$  the other;

And  $x^2 + (a - x)^2 = 2x^2 + a^2 - 2ax = b$  by the question,

Or  $x^2 + \frac{1}{2}a^2 - ax = \frac{1}{2}b$  by division,

Or  $x^2 - ax = \frac{1}{2}b - \frac{1}{2}a^2$  by transposition;

Then  $x^2 - ax + \frac{1}{4}a^2 = \frac{1}{2}b - \frac{1}{4}a^2$  by compl. the sq.

Hence  $x - \frac{1}{2}a = \pm \frac{1}{2}\sqrt{2b - a^2}$  by extracting the root;

Theref.  $x = \frac{1}{2}a \pm \frac{1}{2}\sqrt{2b - a^2}$  the two numbers.

That

That is,  $x = \frac{1}{2}a + \frac{1}{2}\sqrt{2b - a^2}$  the greater number,  
 And  $x = \frac{1}{2}a - \frac{1}{2}\sqrt{2b - a^2}$  the less number.

Hence these two theorems, being put into numbers, give 7 and 3, for the numbers required.

4. Sold a piece of cloth for 24*l.* and gained as much *per cent.* as the cloth cost me ; what was the price of the cloth ?

Let  $x$  = pounds the cloth cost,  
 Then  $24 - x$  = whole gain,  
 But  $100 : x :: x : 24 - x$  by the question,  
 Or  $x^2 = 100 \times 24 - x = 2400 - 100x$ ;  
 That is,  $x^2 + 100x = 2400$ ;  
 Then  $x^2 + 100x + 2500 = 4900$  by compl. the sq.  
 And  $x + 50 = \sqrt{4900} = 70$  by extraction of roots,  
 Consequently  $x = 70 - 50 = 20l.$  = price of the cloth.

5. A person bought a number of oxen for 80*l.* and if he had bought 4 more for the same money, he would have paid 1*l.* less for each : how many did he buy ?

Let the number of oxen be represented by  $x$ ,

Then will  $\frac{80}{x}$  be the price of each,

And  $\frac{80}{x+4}$  = price of each, if  $x+4$  had cost 80*l.*

But  $\frac{80}{x} = \frac{80}{x+4} + 1$  by the question,

Or  $80 = \frac{80x}{x+4} + x$ , by multiplication,

Or  $80x + 320 = 80x + x^2 + 4x$ , by the same,

That is,  $x^2 + 4x = 320$ ;

Then  $x^2 + 4x + 4 = 324$  by completing the square,

And  $x + 2 = \sqrt{324} = 18$  by evolution,

Conseq.  $x = 18 - 2 = 16$ , the numb. of oxen required.

6. What two numbers are those, whose sum, product, and difference of their squares, are all equal to each other ?

Let  $x$  = the greater number,

And  $y$  = the less,

Then  $\left\{ \begin{array}{l} x+y = xy \\ x+y = x^2 - y^2 \end{array} \right\}$  by the question ;

Hence  $1 = \frac{x^2 - y^2}{x+y} = x-y$ , or  $x = y+1$  from the  
 2d equation,

Also  $y + 1 + y = y + 1 \times y$  from the first equation,

$$\text{Or } 2y + 1 = y^2 + y,$$

$$\text{That is, } y^2 - y = 1;$$

Then  $y^2 - y + \frac{1}{4} = 1\frac{1}{4}$  by completing the square,

Also  $y - \frac{1}{2} = \sqrt{1\frac{1}{4}} = \sqrt{\frac{5}{4}} = \frac{1}{2}\sqrt{5}$  by evolution,

$$\text{Consequently } y = \frac{1}{2}\sqrt{5} + \frac{1}{2},$$

$$\text{And } x = y + 1 = \frac{1}{2}\sqrt{5} + \frac{3}{2}.$$

And if these expressions be turned into numbers, we shall

$$\text{have } x = 2.6180 +$$

$$\text{and } y = 1.6180 +$$

7. There are four numbers in arithmetical progression, of which the product of the two extremes is 45, and that of the means 77; what are the numbers?

Let  $x$  = the less extreme,

and  $y$  = the common difference;

Then  $x, x+y, x+2y, x+3y$ , will be the four numbers,

Hence  $x \times x+3y = x^2 + 3xy = 45$ ,      } by the

And  $x+y \times x+2y = x^2 + 3xy + 2y^2 = 77$  } question,

Hence  $2y^2 = 77 - 45 = 32$  by subtraction,

And  $y^2 = \frac{32}{2} = 16$  by division,

Or  $y = \sqrt{16} = 4$  by evolution;

Therefore  $x^2 + 3xy = x^2 + 12x = 45$  by the 1st equation,

And  $x^2 + 12x + 36 = 45 + 36 = 81$  by compl. the sq.

Also  $x + 6 = \sqrt{81} = 9$  by the extraction of roots;

Conseq.  $x = 9 - 6 = 3$ ,

And the numbers are 3, 7, 11, and 15.

8. To find 3 numbers in geometrical progression, whose sum shall be 14, and the sum of their squares 84.

Let  $x, y$ , and  $z$  be the three numbers sought,

Then  $xz = y^2$  by the nature of proportion,

And  $\left\{ \begin{array}{l} x + y + z = 14 \\ x^2 + y^2 + z^2 = 84 \end{array} \right.$  by the question;

Hence  $x + z = 14 - y$  by the second equation,

And  $x^2 + 2xz + z^2 = 196 - 28y + y^2$  by squaring,

Or  $x^2 + z^2 + 2y^2 = 196 - 28y + y^2$  by putting  $2y^2$  for its equal  $2xz$ ,

That is,  $x^2 + z^2 + y^2 = 196 - 28y$  by subtraction,

Or  $196 - 28y = 84$  by equality,

Hence  $y = \frac{196 - 84}{28} = 4$  by transposition and division.

Again,

Again,  $xz = y^2 = 16$ , or  $x = \frac{16}{z}$  by the 1st equation,

And  $x + y + z = \frac{16}{z} + 4 + z = 14$  by the 2d equation,

Or  $16 + 4z + z^2 = 14z$ , or  $z^2 - 10z = -16$ ;

Then  $z^2 - 10z + 25 = 25 - 16 = 9$  by compl. sq.

And  $z - 5 = \pm\sqrt{9} = \pm 3$ , by extracting the roots;

Hence  $z = 5 \pm 3 = 8$  and  $2$ , the two other numbers,

That is,  $x = 2$ , and  $z = 8$ ,

And the three numbers are  $2, 4, 8$ .

#### QUESTIONS FOR PRACTICE.

1. What two numbers are those, whose sum is  $20$ , and their product  $36$ ? Ans.  $2$  and  $18$ .

2. To divide the number  $60$  into two such parts, that their product may be to the sum of their squares, in the ratio of  $2$  to  $5$ . Ans.  $20$  and  $40$ .

3. The difference of two numbers is  $3$ , and the difference of their cubes is  $117$ ; what are those numbers?

Ans.  $2$  and  $5$ .

4. A company at a tavern had  $8l. 15s.$  to pay for their reckoning; but, before the bill was settled, two of them left the room, and then those who remained had  $10s.$  a-piece more to pay than before: how many were there in company?

Ans.  $7$ .

5. A grazier bought as many sheep as cost him  $60l.$  and, after reserving  $15$  out of the number, he sold the remainder for  $54l.$  and gained  $2s.$  a head by them; how many sheep did he buy? Ans.  $75$ .

6. There are two numbers whose difference is  $15$ , and half their product is equal to the cube of the lesser number; what are those numbers? Ans.  $3$  and  $18$ .

7. A person bought cloth for  $33l. 15s.$  which he sold again at  $2l. 8s.$  per piece, and gained by the bargain as much as one piece cost him; required the number of pieces?

Ans.  $15$ .

8. What number is that, which, when divided by the product of its two digits, the quotient is  $3$ ; and if  $18$  be added to it, the digits will be inverted? Ans.  $24$ .

9. What two numbers are those, whose sum multiplied by the greater is equal to  $77$ ; and whose difference multiplied by the lesser is equal to  $12$ ? Ans.  $4$  and  $7$ .

10. To

10. To find a number such, that if you subtract it from 10, and multiply the remainder by the number itself, the product shall be 21. Anf. 7 or 3.

11. To divide 100 into two such parts, that the sum of their square roots may be 14. Anf. 64 and 36.

12. It is required to divide the number 24 into two such parts, that their product may be equal to 35 times their difference. Anf. 10 and 14.

13. The sum of two numbers is 8, and the sum of their cubes is 152; what are the numbers? Anf. 3 and 5.

14. The sum of two numbers is 7, and the sum of their 4th powers is 641; what are the numbers? Anf. 2 and 5.

15. The sum of two numbers is 6, and the sum of their 5th powers is 1056; what are the numbers? Anf. 2 and 4.

16. The sum of four numbers in arithmetical progression is 56, and the sum of their squares is 864; what are the numbers? Anf. 8, 12, 16, and 20.

17. To find four numbers in geometrical progression, whose sum is 15, and the sum of their squares 85?

Anf. 1, 2, 4, and 8.

18. It is required to find four numbers in arithmetical progression, such that their common difference may be 4, and their continued product 176985.

Anf. 15, 19, 23, and 27.

19. Two partners, A and B, gained 140*l.* by trade; A's money was 3 months in trade, and his gain was 60*l.* less than his stock; and B's money, which was 50*l.* more than A's, was in trade 5 months; what was A's stock?

Anf. 100*l.*

## RESOLUTION OF CUBIC AND HIGHER EQUATIONS.

A CUBIC Equation, or Equation of the 3d degree or power, is one that contains the third power of the unknown quantity. As  $x^3 - ax^2 + bx = c$ .

A Biquadratic, or Double Quadratic, is an equation that contains the 4th power of the unknown quantity:

$$\text{As } x^4 - ax^3 + bx^2 + cx = d.$$

An

An Equation of the 5th Power or Degree, is one that contains the 5th power of the unknown quantity:

$$\text{As } x^5 - ax^4 + bx^3 - cx^2 + dx = c.$$

An Equation of the 6th Power or Degree, is one that contains the 6th power of the unknown quantity:

$$\text{As } x^6 - ax^5 + bx^4 - cx^3 + dx^2 - ex = f.$$

And so on, for all other higher powers. Where it is to be noted, however, that all the powers, or terms, in the equation, are supposed to be freed from surds or fractional exponents.

There are many particular and prolix rules usually given for the resolution of some of the above-mentioned powers or equations. But they may be all easily resolved by the following easy rule of Double Position, sometimes called Trial-and-Error.

#### RULE.

1. FIND, by trial, two numbers, as near the true root as you can, and substitute them separately in the given equation, instead of the unknown quantity; marking the errors which arise from each of them.

2. Multiply the difference of the two numbers, found or taken by trial, by the least error, and divide the product by the difference of the errors, when they are alike, but by their sum when they are unlike. Or say, As the difference or sum of the errors is to the difference of the two numbers, so is the least error to the correction of its supposed number.

3. Add the quotient, last found, to the number belonging to the least error, when that number is too little, but subtract it when too great, and the result will give the true root *nearly*.

4. Take this root and the nearest of the two former, or any other that may be found nearer; and, by proceeding in like manner as above, a root will be had still nearer than before; and so on to any degree of exactness required.

*Note 1.* It is best to employ always two assumed numbers that shall differ from each other only by unity in the last figure on the right hand; because then the difference, or multiplier, is only 1.

*Note 2.* The above rule is the 2d rule for Double Position, given in the Arithmetic, page 138 (where it is demonstrated): it is the easiest to be used here; and each new operation commonly doubles the number of true figures in the root.

## EXAMPLES.

Ex. 1. To find the root of the cubic equation  $x^3 + x^2 + x = 100$ , or the value of  $x$  in it.

Here it is soon found that  $x$  lies between 4 and 5. Again, suppose 4.2 and 4.3, and repeat the work as follows:

bers, and the operation will be as follows;

1st Sup.	2d Sup.	1st Sup.	2d Sup.
4 - - - $x$ - - -	5	4.2 - - $x$ - - -	4.3
16 - - - $x^2$ - - -	25	17.64 - - $x^2$ - - -	18.49
64 - - - $x^3$ - - -	125	74.088 - - $x^3$ - - -	79.507
84 - sums - - -	155	95.928 - sums - - -	102.297
- 16 - errors - - -	+ 55	- 4.072 - errors - - -	+ 2.297

the sum of which is 71.

Then as  $71 : 1 :: 16 : \cdot 225$ .

Hence  $x = 4.225$  nearly.

the sum of which is 6.369.	As 6.369 : 1 :: 2.297 : 0.036
Then taken from - 4.300	
leaves $x$ nearly = 4.264	

Again, suppose 4.264, and 4.265, and work as follows:

4.264	-	$x$	-	4.265
18.181696	-	$x^2$	-	18.190225
77.526752	-	$x^3$	-	77.581310
99.972448	-	sums	-	100.036535
- 0.027552	-	errors	-	+ 0.036535

the sum of which is .064087.

Then as .064087 : .001 :: .027552 : 0.0004299

To this adding - 4.264

gives  $x$  very nearly = 4.2644299

The work of the example above might have been much shortened, by the use of the Table of Powers at p. 90, &c., which would have given two or three figures by inspection. But the example has been worked out so particularly as it is, the better to shew the method.

Ex. 2. To find the root of the equation  $x^3 - 15x^2 + 63x = 50$ , or the value of  $x$  in it.

Here it soon appears that  $x$  is very little above 1.

Suppose

Suppose therefore 1.0 and 1.1 and work as follows : Again, suppose the two numbers 1.03 and 1.02, &c, as follows :

1·0	-	$x$	-	1·1
63·0	-	$63x$	-	69·3
-15	-	$-15x$	-	18·15
1	-	$x$	-	1·33
49	-	sums	-	52·481
-1	-	errors	-	+2·481
3·481	sum of the errors.			
As 3·481:1::1:·03 correct				1·00

Hence  $x = 1.03$  nearly.

Again, suppose the two numbers 1·03 and 1·02, &c, as follows:

1.03	-	$x$	-	1.02
64.89	-	$63x$	64.26	
- 15.9135	-	$15x^2$	- 15.6060	
1.092727	$x^3$		1.061203	
56.069227	fums	49.715208		
+ .069227	errors	- .284792		
.284792				
As .354019	: .01	:: .069227		
				.0019555
This taken from		1.03		
leaves $x$ nearly = 1.02804				

*Note 3.* Every equation has as many roots as it contains dimensions, or as there are units in the index of its highest power. That is, a simple equation has only one value of the root; but a quadratic equation has two values or roots, a cubic equation has three roots, a biquadratic equation has four roots, and so on.

And when one of the roots of an equation has been found by approximation, as above, the rest may be found as follows. — Take, for a dividend, the given equation, with the known term transposed, with its sign changed, to the unknown side of the equation; and, for a divisor, take  $x$  minus the root just found. Divide the said dividend by the divisor, and the quotient will be the equation depressed a degree lower than the given one.

Find a root of this new equation by approximation, as before, or otherwise, and it will be a second root of the original equation. Then, by means of this root, depress the second equation one degree lower, and from thence find a third root, and so on, till the equation be reduced to a quadratic; then the two roots of this being found, by the method of completing the square, they will make up the remainder of the roots. Thus, in the foregoing equation, having found one root to be 1.02804, connect it by minus with  $x$  for a divisor, and the equation for a dividend, &c, as follows:

$$(x - 1.02804)x^3 - 15x^2 + 63x - 50(x^2 - 13.97196x + 48.63627) = 0.$$

Then the two roots of this quadratic equation, or  $x^2 - 13.97196x = -48.63627$ , by completing the square, are 6.57653 and 7.39543, which are also the other two roots of the given cubic equation. So that all the three roots of that equation, viz.  $x^3 - 15x^2 + 63x = 50$ ,

are  $1 \cdot 02804$   
and  $6 \cdot 57653$   
and  $7 \cdot 39543$   
sum  $15 \cdot 00000$

and the sum of all the roots is found to  
be 15, being equal to the co-efficient of  
the 2d term of the equation, which the  
sum of the roots always ought to be, when  
they are right.

*Note 4.* It is also a particular advantage of the foregoing rule, that it is not necessary to prepare the equation, as for other rules, by reducing it to the usual final form and state of equations. Because the rule may be applied at once to an unreduced equation, though it be ever so much embarrassed by surd and compound quantities. As in the following example:

**Ex. 3.** Let it be required to find the root  $x$  of the equation  $\sqrt{144x^2 - (x^2 + 20)^2} + \sqrt{196x^2 - (x^2 + 24)^2} = 114$ , or the value of  $x$  in it.

By a few trials, it is soon found that the value of  $x$  is but little above 7. Suppose, therefore, first, that  $x$  is = 7, and then  $x$  = 8.

First, when  $x = 7$ ,

Second, when  $x = 8$ .

47.906	-	$\sqrt{144x^2 - (x^3 + 20)^2}$	-	46.476
65.384	-	$\sqrt{196x^2 - (x^2 + 24)^2}$	-	69.283
113.290	-	the sums of these	-	115.759
114.000	-	the true number	-	114.000
-0.710	-	the two errors	-	+1.759
+1.759				

$x = 7.2$  nearly

Suppose

Suppose again  $x = 7\cdot2$ , and then, because it turns out too great, suppose  $x$  also  $= 7\cdot1$ , &c, as follows :

Supp. $x = 7\cdot2$	Supp. $x = 7\cdot1$
$47\cdot990 - \sqrt{144x^2 - (x^2 + 20)^2} = 47\cdot973$	
$66\cdot402 - \sqrt{196x^2 - (x^2 + 20)^2} = 65\cdot904$	
<hr/>	<hr/>
$114\cdot392 - \text{the sums of these} = 113\cdot877$	
$114\cdot000 - \text{the true number} = 114\cdot000$	
<hr/>	<hr/>
$+0\cdot392 - \text{the errors} = -0\cdot123$	
$0\cdot123$	
<hr/>	<hr/>

As  $.515 : .123 :: 1 : .024$  the correction,  
 $7\cdot100$

Therefore  $x = 7\cdot124$  nearly the root required.

*Note 5.* The same rule also, among other more difficult forms of equations, succeeds very well in what are called exponential ones, or those which have an unknown quantity in the exponent of the power ; as in the following example :

Ex. 4. To find the value of  $x$  in the exponential equation  $x^x = 100$ .

For more easily solving such kind of equations, it is convenient to take the logarithms of them, and then compute the terms by means of a table of logarithms. Thus, the logarithms of the two sides of the present equation are,  $x \times \log. \text{ of } x = 2$  the log. of 100. Then, by a few trials it is soon perceived that the value of  $x$  is somewhere between the two numbers 3 and 4, and indeed nearly in the middle between them, but rather nearer the latter than the former. Taking therefore first  $x = 3\cdot5$ , and then  $= 3\cdot6$ , and working with the logarithms, the operation will be as follows :

First Supp. $x = 3\cdot5$ .	Second Supp. $x = 3\cdot6$ .
Log. of $3\cdot5 = 0\cdot544068$	Log. of $3\cdot6 = 0\cdot556303$
then $3\cdot5 \times \log. 3\cdot5 = 1\cdot904238$	then $3\cdot6 \times \log. 3\cdot6 = 2\cdot002689$
the true number $2\cdot000000$	the true number $2\cdot000000$
<hr/>	<hr/>
error, too little, $-0\cdot095762$	error, too great, $+\cdot002689$
$002689$	
<hr/>	<hr/>
$\cdot098451$ sum of the errors. Then,	
<hr/>	

As .093451 : .1 :: .002689 : 0.00273 the correction  
taken from 3.60000  
leaves - 3.59727 =  $x$  nearly.

On trial, this is found to be a very small matter too little.  
Take therefore again,  $x = 3.59727$ , and next = 3.59728,  
and repeat the operation as follows :

First, Supp. $x = 3.59727$ . Log. of 3.59727 is 0.555973 $3.59727 \times \log.$ of 3.59727 = 1.9999854 the true number 2.0000000	Second, Supp. $x = 3.59728$ . Log. of 3.59728 is 0.555974 $3.59728 \times \log.$ of 3.59728 = 1.9999953 the true number 2.0000000
error, too little, -0.0000146 - 0.0000047	error, too little, -0.0000047

0.0000099 diff. of the errors. Then,

As .0000099 : .00001 :: .0000047 : 0.00000474747 the cor.  
added to - 3.59728000000

gives nearly the value of  $x = 3.59728474747$

Ex. 5. To find the value of  $x$  in the equation  $x^3 + 10x^2 + 5x = 260$ . Ans.  $x = 4.1179857$ .

Ex. 6. To find the value of  $x$  in the equation  $x^3 - 2x = 50$ . Ans. 3.8649854.

Ex. 7. To find the value of  $x$  in the equation  $x^3 + 2x^2 - 23x = 70$ . Ans.  $x = 5.13457$ .

Ex. 8. To find the value of  $x$  in the equation  $x^3 - 17x^2 + 54x = 350$ . Ans.  $x = 14.95407$ .

Ex. 9. To find the value of  $x$  in the equation  $x^4 - 3x^2 - 75x = 10000$ . Ans.  $x = 10.2609$ .

Ex. 10. To find the value of  $x$  in the equation  $2x^4 - 16x^3 + 40x^2 - 30x = -1$ . Ans.  $x = 1.284724$ .

Ex. 11. To find the value of  $x$  in the equation  $x^5 + 2x^4 + 3x^3 + 4x^2 + 5x = 54321$ . Ans.  $x = 8.414455$ .

Ex. 12. To find the value of  $x$  in the equation  $x^x = 123456789$ . Ans.  $x = 8.6409263$ .

Ex. 13. Given  $2x^4 - 7x^3 + 11x^2 - 3x = -11$ , to find  $x$ .

Ex. 14. To find the value of  $x$  in the equation  $(3x^2 - 2\sqrt{x} + 1)^{\frac{3}{2}} - (x^2 - 4x\sqrt{x} + 3\sqrt{x})^{\frac{5}{2}} = 56$ . Ans.  $x = 18.360877$ .

## OF SIMPLE INTEREST.

As the interest of any sum, for any time, is directly proportional to the principal sum, and to the time; therefore the interest of 1 pound, for 1 year, being multiplied by any given principal sum, and by the time of its forbearance, in years and parts, will give its interest for that time. That is, if there be put

$r$  = the rate of interest of 1 pound per annum,

$p$  = any principal sum lent,

$t$  = the time it is lent for, and

$a$  = the amount or sum of principal and interest ; then  
is  $prt$  = the interest of the sum  $p$ , for the time  $t$ , and conseq.  
 $p + prt$  or  $p \times (1 + rt) = a$ , the amount for that time.

From this expression, other theorems can easily be deduced, for finding any of the quantities above mentioned : which theorems, collected altogether, will be as below ;

1st,  $a = p + prt$ , the amount,

2d,  $p = \frac{a}{1 + rt}$ , the principal,

3d,  $r = \frac{a - p}{pt}$ , the rate,

4th,  $t = \frac{a - p}{pr}$ , the time.

*For Example.* Let it be required to find, in what time any principal sum will double itself, at any rate of simple interest.

In this case, we must use the first theorem,  $a = p + prt$ , in which the amount  $a$  must be made =  $2p$ , or double the principal, that is,  $p + prt = 2p$ , or  $prt = p$ , or  $rt = 1$  ; and hence  $t = \frac{1}{r}$ .

Here,  $r$  being the interest of 1*l.* for 1 year, it follows, that the doubling at simple interest, is equal to the quotient of any sum divided by its interest for 1 year. So, if the rate of interest be 5 per cent. then  $100 \div 5 = 20$ , is the time of doubling at that rate.

Or the 4th theorem gives at once

$$t = \frac{a - p}{pr} = \frac{2p - p}{pr} = \frac{2 - 1}{r} = \frac{1}{r}, \text{ the same as before.}$$

## COMPOUND INTEREST.

BESIDE the quantities concerned in Simple Interest, namely,

$p$  = the principal sum,

$r$  = the rate of interest of 1*l.* for 1 year,

$a$  = the whole amount of the principal and interest,

$t$  = the time,

there is another quantity employed in Compound Interest, viz. the ratio of the rate of interest, which is the amount of 1*l.* for 1 time of payment, and which here let be denoted by  $R$ , viz.

$R = 1 + r$ , the amount of 1*l.* for 1 time.

Then the particular amounts for the several times may be thus computed, viz. As 1*l.* is to its amount for any time, so is any proposed principal sum, to its amount for the same time ; that is, as

1*l.* :  $R$  ::  $p$  :  $pR$ , the 1st year's amount,

1*l.* :  $R$  ::  $pR$  :  $pR^2$ , the 2d year's amount,

1*l.* :  $R$  ::  $pR^2$  :  $pR^3$ , the 3d year's amount,

and so on.

Therefore, in general,  $pR^t = a$  is the amount for the  $t$  year, or  $t$  time of payment. From whence the following general theorems are deduced :

1st,  $a = pR^t$ , the amount.

2d,  $p = \frac{a}{R^t}$  the principal,

3d,  $R = \sqrt[t]{\frac{a}{p}}$ , the ratio,

4th,  $t = \frac{\log. \text{ of } a - \log. \text{ of } p}{\log. \text{ of } R}$ , the time.

From which, any one of the quantities may be found, when the rest are given.

As to the whole interest, it is found by barely subtracting the principal  $p$  from the amount  $a$ .

*Example.* Suppose it be required to find, in how many years any principal sum will double itself, at any proposed rate of compound interest.

In this case the 4th theorem must be employed, making  $a = 2p$ ; and then it is

$$t = \frac{\text{l. } a - \text{l. } p}{\log R} = \frac{\text{l. } 2p - \text{l. } p}{\log R} = \frac{\log 2}{\log R}.$$

So, if the rate of interest be 5 per cent. per annum; then  $R = 1 + .05 = 1.05$ ; and hence,

$$t = \frac{\log 2}{\log 1.05} = \frac{.301030}{.021189} = 14.2067 \text{ nearly};$$

that is, any sum doubles itself in  $14\frac{1}{5}$  years nearly, at the rate of 5 per cent. per annum compound interest.

From hence, and from the like question in Simple Interest, above given, are deduced the times in which any sum doubles itself, at several rates of interest, both simple and compound; viz.

At		At Simp. Int.	At Comp. Int.
		Years.	Years.
2		50	35.0028
$2\frac{1}{2}$		40	28.0701
3	per cent. per annum	$33\frac{1}{3}$	23.4498
$3\frac{1}{2}$	interest, 1 <i>t</i> , or any	$28\frac{4}{7}$	20.1488
4	other sum, will	25	17.6730
$4\frac{1}{2}$	double itself in the	$22\frac{2}{9}$	15.7473
5	following years.	20	14.2067
6		$16\frac{2}{3}$	11.8957
7		$14\frac{4}{7}$	10.2448
8		$12\frac{1}{2}$	9.0065
9		$11\frac{1}{9}$	8.0432
10		10	7.2725

The following Table will very much facilitate the calculation of the compound interest of any sum, for any number of years, at various rates of interest.

The Amounts of  $1l.$  in any Number of Years.

Yrs.	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	6
1	1.0300	1.0350	1.0400	1.0450	1.0500	1.0600
2	1.0609	1.0712	1.0816	1.0900	1.1025	1.123
3	1.0927	1.1087	1.1249	1.1412	1.1576	1.19
4	1.1255	1.1475	1.1699	1.1925	1.2155	1.225
5	1.1593	1.1877	1.2157	1.2462	1.2763	1.3382
6	1.1941	1.2292	1.2653	1.3023	1.3401	1.4185
7	1.2299	1.2723	1.3159	1.3609	1.4071	1.5035
8	1.2668	1.3168	1.3686	1.4221	1.4775	1.5939
9	1.3048	1.3629	1.4233	1.4861	1.5513	1.6895
10	1.3439	1.4105	1.4802	1.5536	1.6289	1.7909
11	1.3842	1.4600	1.5395	1.6229	1.7103	1.8933
12	1.4258	1.5111	1.6010	1.6959	1.7959	2.0122
13	1.4685	1.5640	1.6651	1.7722	1.8856	2.1329
14	1.5126	1.6187	1.7317	1.8519	1.9799	2.2309
15	1.5580	1.6753	1.8009	1.9353	2.0789	2.3966
16	1.6047	1.7340	1.8730	2.0224	2.1829	2.5404
17	1.6520	1.7947	1.9479	2.1134	2.2920	2.6928
18	1.7024	1.8575	2.0253	2.2085	2.4066	2.8543
19	1.7535	1.9225	2.1068	2.3078	2.5270	3.0256
20	1.8061	1.9898	2.1911	2.4117	2.6543	3.2071

The use of this Table, which contains all the powers,  $R^t$ , to the 20th power, or the amounts of  $1l.$  is chiefly to calculate the interest, or the amount of any principal sum, for any time, not more than 20 years.

For example, let it be required to find, to how much  $523l.$  will amount in 15 years, at the rate of 5 per cent. per annum compound interest.

In the table, on the line 15, and in the column 5 per cent.

is the amount of  $1l.$ , viz. - - - 2.0789

this multiplied by the principal - - 523

gives the amount - - - - 1087.247

or - - - - 1087l. 5s.  $3\frac{1}{4}d.$

and therefore the interest is - - 564l. 5s.  $3\frac{1}{4}d.$

*Note 1.* When the rate of interest is to be determined to any other time than a year; as suppose to  $\frac{1}{2}$  a year, or  $\frac{1}{4}$  a year, &c; the rules are still the same; but then  $t$  will express that time, and  $R$  must be taken the amount for that time.

*Note 2.* When the compound interest, or amount, of any sum, is required for the parts of a year; it may be determined in the following manner:

1<sup>st</sup>, For any time which is some aliquot part of a year:— Find the amount of 1*l.* for 1 year, as before; then that root of it which is denoted by the aliquot part, will be the amount of 1*l.* This amount being multiplied by the principal sum, will produce the amount of the given sum as required.

2<sup>d</sup>, When the time is not an aliquot part of a year:— Reduce the time into days, and take the 365th root of the amount of 1*l.* for 1 year, which will give the amount of the same for 1 day. Then raise this amount to that power whose index is equal to the number of days, and it will be the amount for that time. Which amount being multiplied by the principal sum, will produce the amount of that sum as before.

And in these calculations, the operation by logarithms will be very useful.

## OF ANNUITIES.

**ANNUITY** is a term used for any periodical income, arising from money lent, or from houses, lands, salaries, pensions, &c. payable from time to time, but mostly by annual payments.

Annuities are divided into those that are in Possession, and those in Reversion: the former meaning such as have commenced; and the latter such as will not begin till some particular event has happened, or till after some certain time has elapsed.

When an annuity is forborn for some years, or the payments not made for that time, the annuity is said to be in **Arrears.**

An annuity may also be for a certain number of years; or it may be without any limit, and then it is called a **Perpetuity.**

The Amount of an annuity, forborn for any number of years, is the sum arising from the addition of all the annuities for that number of years, together with the interest due upon each after it becomes due.

The Present Worth or Value of an annuity, is the price or sum which ought to be given for it, supposing it to be bought off, or paid all at once.

Let  $a$  = the annuity, pension, or yearly rent.

$n$  = the number of years forborn, or lent for.

$R$  = the amount of 1*l.* for 1 year.

$m$  = the amount of the annuity.

$v$  = its value, or its present worth.

Now, 1 being the present value of the sum  $R$ , by proportion the present value of any other sum  $a$ , is thus found:

as  $R : 1 :: a : \frac{a}{R}$  the present value of  $a$  due 1 year hence.

In like manner  $\frac{a}{R^2}$  is the present value of  $a$  due 2 years;

hence; for  $R : 1 :: \frac{a}{R} : \frac{a}{R^2}$ . So also  $\frac{a}{R^3}, \frac{a}{R^4}, \frac{a}{R^5}, \&c.$ , will be the present values of  $a$ , due at the end of 3, 4, 5, &c., years respectively. Consequently the sum of all these, or  $\frac{a}{R} + \frac{a}{R^2} + \frac{a}{R^3} + \frac{a}{R^4} + \&c. = (\frac{1}{R} + \frac{1}{R^2} + \frac{1}{R^3} + \frac{1}{R^4}, \&c.) \times a$ , continued to  $n$  terms, will be the present value of all the  $n$  years' annuities. And the value of the perpetuity, is the sum of the series to infinity.

But this series, it is evident, is a geometrical progression, having  $\frac{1}{R}$  both for its first term and common ratio, and the number of its terms  $n$ ; therefore the sum  $v$  of all the terms, or the present value of all the annual payments, will be

$$v = \frac{\frac{1}{R} - \frac{1}{R} \times \frac{1}{R^n}}{1 - \frac{1}{R}} \times a, \text{ or } = \frac{R^n - 1}{R - 1} \times \frac{a}{R^n}.$$

When the annuity is a perpetuity;  $n$  being infinite,  $R^n$  is also infinite, and therefore the last quantity  $\frac{1}{R^n}$  becomes = 0,

therefore  $\frac{a}{R - 1} \times \frac{1}{R^n}$  also = 0; consequently the expression becomes barely  $v = \frac{a}{R - 1}$ ; that is, any annuity divided by the interest of 1*l.* for 1 year, gives the value of the perpetuity. So, if the rate of interest be 5 per cent,

Then  $100a \div 5 = 20a$  is the value of the perpetuity at 5 per cent;

Also

Also  $100a \div 4 = 25a$  is the value of the perpetuity at 4 per cent:

And  $100a \div 3 = 33\frac{1}{3}a$  is the value of the perpetuity at 3 per cent: and so on.

Again, because the amount of 1*l.* in *n* years, is  $R^n$ , its increase in that time will be  $R^n - 1$ ; but its interest for one single year, or the annuity answering to that increase, is  $R - 1$ ; therefore as  $R - 1$  is to  $R^n - 1$ , so is *a* to *m*; that

$$\text{is, } m = \frac{R^n - 1}{R - 1} \times a.$$

Hence, the several cases relating to Annuities in Arrear, will be resolved by the following equations :

$$m = \frac{R^n - 1}{R - 1} \times a = vR^n$$

$$v = \frac{R^n - 1}{R - 1} \times \frac{a}{R^n} = \frac{m}{R^n}$$

$$a = \frac{R - 1}{R^n - 1} \times m = \frac{R - 1}{R^n - 1} \times vR^n$$

$$n = \frac{\log. m - \log. v}{\log. R} = \frac{\log. \frac{mR - m + a}{a}}{\log. R}$$

$$\text{Log. } R = \frac{\log. m - \log. v}{n}$$

$$r = \left( \frac{1}{R^p} - \frac{1}{R^n} \right) \times \frac{a}{R - 1}.$$

In this last theorem, *r* denotes the present value of an annuity in reversion, after *p* years, or not commencing till after the first *p* years, being found by taking the difference between the two values  $\frac{R^n - 1}{R - 1} \times \frac{a}{R^n}$  and  $\frac{R^p - 1}{R - 1} \times \frac{a}{R^p}$  for *n* years and *p* years.

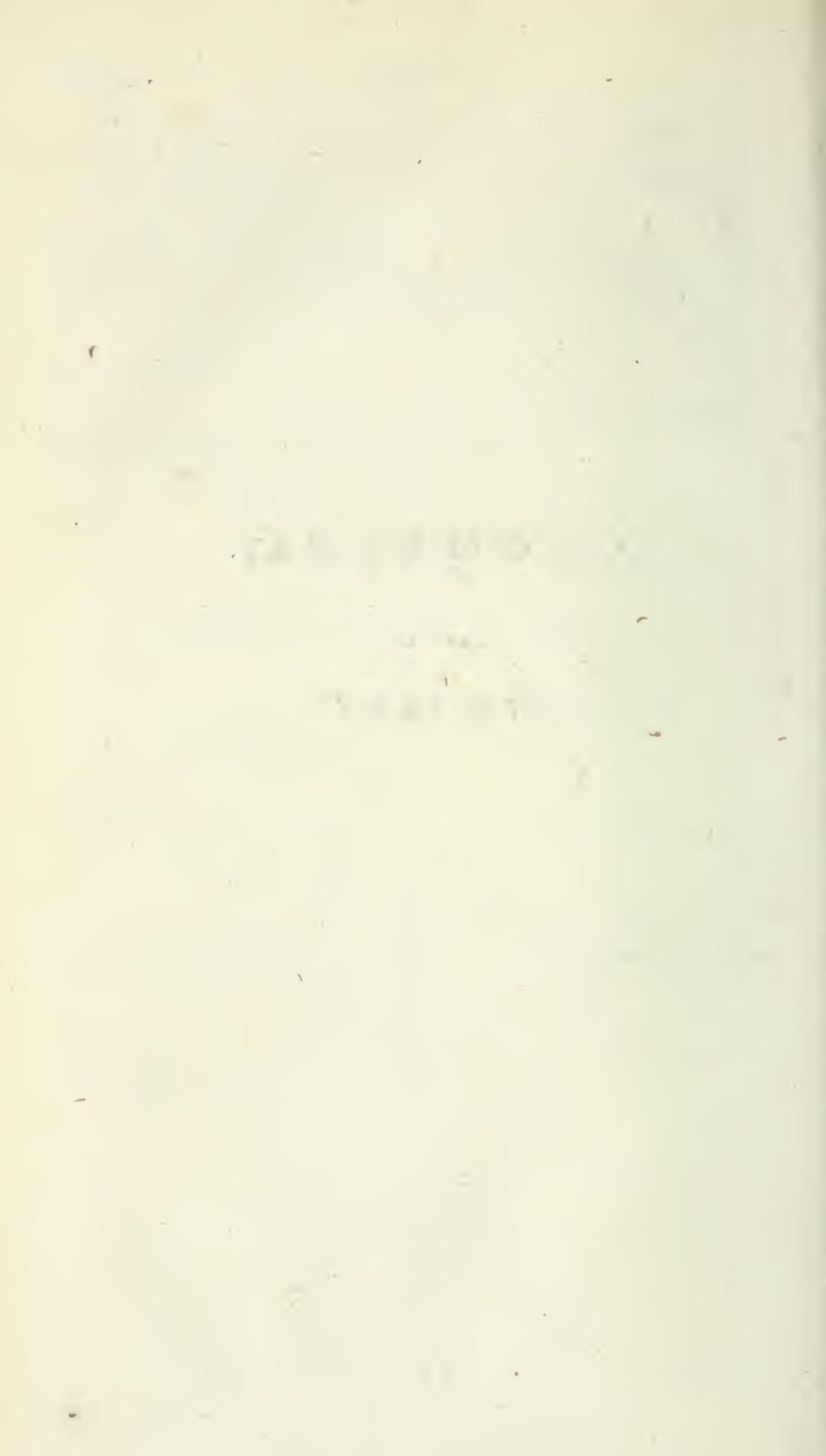
GEOMETRY;

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# GEOMETRY.

## DEFINITIONS.

1. A POINT is that which has position, but no magnitude, nor dimensions; neither length, breadth, nor thickness.

2. A Line is length, without breadth or thickness.

3. A Surface or Superficies, is an extension, or a figure, of two dimensions, length and breadth; but without thickness.

4. A Body or Solid, is a figure of three dimensions, namely, length, breadth, and depth, or thickness.

5. Lines are either Right, or Curved, or Mixed of these two.

6. A Right Line, or Straight Line, lies all in the same direction, between its extremities; and is the shortest distance between two points.

When a Line is mentioned simply, it means a Right Line.

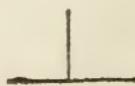
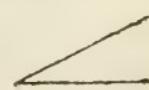
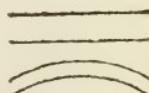
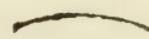
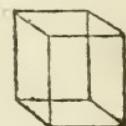
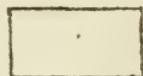
7. A Curve continually changes its direction between its extreme points.

8. Lines are either Parallel, Oblique, Perpendicular, or Tangential.

9. Parallel Lines are always at the same perpendicular distance; and they never meet, though ever so far produced.

10. Oblique lines change their distance, and would meet, if produced, on the side of the least distance.

11. One line is Perpendicular to another, when it inclines not more on the one side than



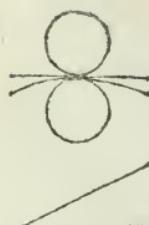
than the other ; or when the angles on both sides of it are equal.

12. A line or circle is Tangential, or a Tangent to a circle, or other curve, when it touches it, without cutting, when both are produced.

13. An Angle is the inclination, or opening of two lines, having different directions, and meeting in a point.

14. Angles are Right or Oblique, Acute or Obtuse.

15. A Right Angle, is that which is made by one line perpendicular to another. Or when the angles on each side are equal to one another, they are right angles.



16. An Oblique Angle, is that which is made by two oblique lines ; and is either less or greater than a right angle.



17. An Acute Angle is less than a right angle.



18. An Obtuse Angle is greater than a right angle.



19. Superficies are either Plane or Curved.

20. A Plane Superficies, or a Plane, is that with which a right line may, every way, coincide. Or, if the line touch the plane in two points, it will touch it in every point. But if not, it is curved.

21. Plane Figures are bounded either by right lines or curves.

22. Plane figures that are bounded by right lines, have names according to the number of their sides, or of their angles ; for they have as many sides as angles ; the least number being three.

23. A figure of Three sides and angles, is called a Triangle. And it receives particular denominations from the relations of its sides and angles.

24. An Equilateral Triangle, is that whose three sides are all equal.



25. An Isosceles Triangle, is that which has two sides equal.

26. A

26. A Scalene Triangle, is that whose three sides are all unequal.

27. A Right-angled Triangle, is that which has one right-angle.

28. Other triangles are Oblique-angled, and are either Obtuse or Acute.

29. An Obtuse-angled Triangle, has one obtuse angle.

30. An Acute-angled Triangle, has all its three angles acute.

31. A figure of Four sides and angles, is called a Quadrangle, or a Quadrilateral.

32. A Parallelogram, is a quadrilateral which has both its pairs of opposite sides parallel. And it takes the following particular names, viz. Rectangle, Square, Rhombus, Rhomboid.

33. A Rectangle is a parallelogram having all its angles right ones.

34. A Square is an equilateral rectangle; having all its sides equal, and its angles right ones.

35. A Rhomboid is an oblique-angled parallelogram.

36. A Rhombus is an equilateral rhomboid; having all its sides equal, but its angles oblique.

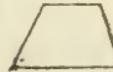
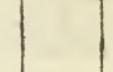
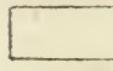
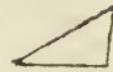
37. A Trapezium is a quadrilateral which hath not its opposite sides parallel.

38. A Trapezoid has only one pair of opposite sides parallel.

39. A Diagonal is a line joining any two opposite angles of a quadrilateral.

40. Plane figures that have More than four sides are, in general, called Polygons: and they receive other particular names, according to the number of their sides or angles. Thus,

41. A Pentagon is a polygon of five sides; a Hexagon, of six sides; a Heptagon, seven; an Octagon, eight; a Nonagon, nine; a Decagon, ten; an Undecagon, eleven; and a Dodecagon, twelve sides.



42. A Regular Polygon has all its sides and all its angles equal.—If they are not both equal, the polygon is Irregular.

43. An Equilateral Triangle is also a Regular Figure of three sides, and the Square is one of four; the former being also called a Trigon, and the latter a Tetragon.

44. A Circle is a plane figure bounded by a curve line, called the Circumference, which is every where equidistant from a certain point within, call'd its Centre.

The circumference itself is often called a circle, and also the Periphery.

45. The Radius of a circle, is a line drawn from the centre to the circumference.

46. The Diameter of a circle, is a line drawn through the centre, and terminating at the circumference on both sides.

47. An Arc of a circle, is any part of the circumference.

48. A Chord, is a right line joining the extremities of an arc.

49. A Segment, is any part of a circle bounded by an arc and its chord.

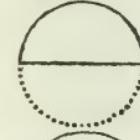
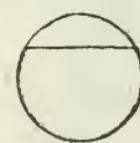
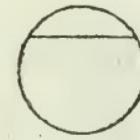
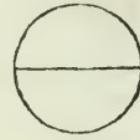
50. A Semicircle, is half the circle, or a segment cut off by a diameter.

The half circumference is sometimes called the Semicircle.

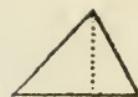
51. A Sector, is any part of a circle which is bounded by an arc, and two radii drawn to its extremities.

52. A Quadrant, or Quarter of a circle, is a sector having a quarter of the circumference for its arc, and its two radii are perpendicular to each other.

A quarter of the circumference is sometimes called a Quadrant.

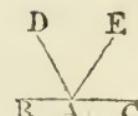


53. The Height or Altitude of a figure, is a perpendicular let fall from an angle, or its vertex, to the opposite side, called the base.



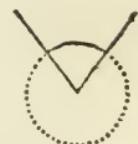
54. In a right-angled triangle, the side opposite the right angle, is called the Hypotenuse; and the other two sides are called the Legs, or sometimes the Base and Perpendicular.

55. When an angle is denoted by three letters, of which one stands at the angular point, and the other two on the two sides, that which stands at the angular point is read in the middle.

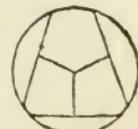


56. The circumference of every circle is supposed to be divided into 360 equal parts, called Degrees; and each degree into 60 Minutes, each minute into 60 Seconds, and so on. Hence a semicircle contains 180 degrees, and a quadrant 90 degrees.

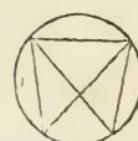
57. The Measure of an angle, is an arc of any circle contained between the two lines which form that angle, the angular point being the centre; and it is estimated by the number of degrees contained in that arc.



58. Lines, or chords, are said to be Equidistant from the centre of a circle, when perpendiculars drawn to them from the centre are equal.



59. And the right line on which the Greater Perpendicular falls, is said to be farther from the centre.



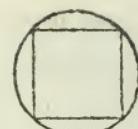
60. An Angle In a segment, is that which is contained by two lines, drawn from any point in the arc of the segment, to the two extremities of that arc.

61. An angle On a segment, or on an arc, is that which is contained by two lines, drawn from any point in the opposite or supplemental part of the circumference, to the extremities of the arc, and containing the arc between them.

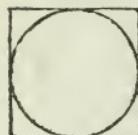


62. An angle at the circumference, is that whose angular point is any where in the circumference. And an angle at the centre, is that whose angular point is at the centre.

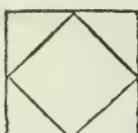
63. A right-lined figure is Inscribed in a circle, or the circle Circumscribes it, when all the angular points of the figure are in the circumference of the circle.



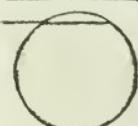
64. A right-lined figure Circumscribes a circle, or the circle is Inscribed in it, when all the sides of the figure touch the circumference of the circle.



65. One right-lined figure is Inscribed in another, or the latter Circumscribes the former, when all the angular points of the former are placed in the sides of the latter.



66. A Secant, is a line that cuts a circle, lying partly within, and partly without it.



67. Identical figures, are such as have all the sides and all the angles of the one, respectively equal to all the sides and all the angles of the other, each to each ; so that if the one figure were applied to, or laid upon the other, all the sides of the one would exactly fall upon and cover all the sides of the other ; the two becoming as it were but one and the same figure.

68. Similar figures, are those that have all the angles of the one equal to all the angles of the other, each to each, and the sides about the equal angles proportional.

69. The Perimeter of a figure, is the sum of all its sides taken together.

70. A Proposition, is something which is either proposed to be done, or to be demonstrated, and is either a problem or a theorem.

71. A Problem, is something proposed to be done.

72. A Theorem, is something proposed to be demonstrated.

73. A Lemma, is something which is premised, or demonstrated, in order to render what follows more easy.

74. A Corollary, is a consequent truth, gained immediately from some preceding truth, or demonstration.

75. A Scholium, is a remark or observation made upon something going before it.

## AXIOMS.

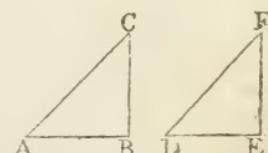
1. THINGS which are equal to the same thing, are equal to each other.
2. When equals are added to equals, the wholes are equal.
3. When equals are taken from equals, the remains are equal.
4. When equals are added to unequals, the wholes are unequal.
5. When equals are taken from unequals, the remains are unequal.
6. Things which are double of the same thing, or equal things, are equal to each other.
7. Things which are halves of the same thing, are equal.
8. Every whole is equal to all its parts taken together.
9. Things which coincide, or fill the same space, are identical, or mutually equal in all their parts.
10. All right angles are equal to one another.
11. Angles that have equal measures, or arcs, are equal.

## THEOREM I.

IF two Triangles have Two Sides and the Included Angle in the one, equal to Two Sides and the Included Angle in the other, the Triangles will be Identical, or equal in all respects.

In the two triangles ABC, DEF, if the side AC be equal to the side DF, and the side BC equal to the side EF, and the angle C equal to the angle F; then will the two triangles be identical, or equal in all respects.

For conceive the triangle ABC to be applied to, or placed on, the triangle DEF, in such manner that the point C may coincide



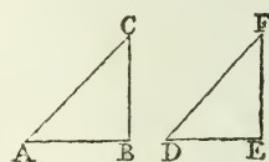
coincide with the point F, and the side AC with the side DF, which is equal to it.

Then, since the angle F is equal to the angle C (by hyp.), the side BC will fall on the side EF. Also, because AC is equal to DF, and BC equal to EF (by hyp.), the point A will coincide with the point D, and the point B with the point E; consequently the side AB will coincide with the side DE; therefore the two triangles are identical, and have all their other corresponding parts equal (ax. 9), namely, the side AB equal to the side DE, the angle A to the angle D, and the angle B to the angle E. — Q. E. D.

### THEOREM II.

TRIANGLES which have Two Angles, and the Side which lies between them, equal, are Identical, or have their other sides and angle equal.

Let the two triangles ABC, DEF, have the angle A equal to the angle D, the angle B equal to the angle E, and the side AB equal to the side DE; then these two triangles will be identical.



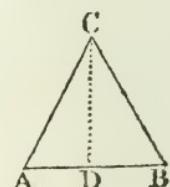
For, conceive the triangle ABC to be placed on the triangle DEF, in such manner that the side AB may fall exactly on the equal side DE. Then, since the angle A is equal to the angle D (by hyp.), the side AC must fall on the side DF; and, in like manner, because the angle B is equal to the angle E, the side BC must fall on the side EF. Thus the three sides of the triangle ABC will be exactly placed on the three sides of the triangle DEF; consequently the two triangles are identical (ax. 9), having the other two sides AC, BC, equal to the two DF, EF, and the remaining angle C equal to the remaining angle F. — Q. E. D.

### THEOREM III.

IN an Isosceles Triangle, the Angles at the Base are equal. Or, if a Triangle have Two Sides equal, their Opposite Angles will also be equal.

If the triangle ABC have the side AC equal to the side BC: then will the angle B be equal to the angle A.

For, conceive the angle C to be bisected, or divided into two equal parts, by the line CD, making the angle ACD equal to the angle BCD.



Then,

Then, the two triangles ACD, BCD, have two sides and the contained angle of the one, equal to two sides and the contained angle of the other, viz. the side AC equal to BC, the angle ACD equal to BCD, and the side CD common; therefore these two triangles are identical, or equal in all respects (th. 1); and consequently the angle A equal to the angle B. Q. E. D.

*Corol.* 1. Hence, the line which bisects the vertical angle of an isosceles triangle, bisects the base, and is also perpendicular to it.

*Corol.* 2. Hence too it appears, that every equilateral triangle is also equiangular, or has all its angles equal.

## THEOREM IV.

If a Triangle have Two of its Angles equal to each other, the Sides Opposite to them will also be equal.

If the triangle ABC, have the angle A equal to the angle B, it will also have the side AC equal to the side BC.

For, conceive the side AB to be bisected in the point D, making AD equal to DB; and join DC, dividing the whole triangle into the two triangles ACD, BCD. Also conceive the triangle ACD to be turned over upon the triangle BCD, so that AD may fall on BD.

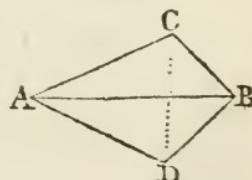
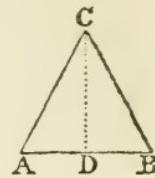
Then, because the line AD is equal to the line DB (by hyp.), the point A coincides with the point B, and the point D with the point D. Also, because the angle A is equal to the angle B (by hyp.), the line AC will fall on the line BC, and the extremity C of the side AC will coincide with the extremity C of the side BC, because DC is common to both; consequently the side AC is equal to BC. Q. E. D.

*Corol.* Hence every equiangular triangle, is also equilateral.

## THEOREM V.

TRIANGLES which have their Three Sides mutually equal, are Identical, or have also their Three Angles equal, each to each.

Let the two triangles ABC, ABD, have their three sides respectively equal, viz. the side AB equal to AB, AC to AD, and BC to BD; then shall the two triangles be identical, or have their angles equal, viz. those angles



that

that are opposite to the equal sides; namely, the angle  $BAC$  to the angle  $BAD$ , the angle  $ABC$  to the angle  $ABD$ , and the angle  $C$  to the angle  $D$ .

For, conceive the two triangles to be joined together by their longest equal sides; and draw the line  $CD$ .

Then, in the triangle  $ACD$ , because the side  $AC$  is equal to  $AD$  (by hyp.), the angle  $ACD$  is equal to the angle  $ADC$  (th. 3). In like manner, in the triangle  $BCD$ , the angle  $BCD$  is equal to the angle  $BDC$ , because the side  $BC$  is equal to  $BD$ . Hence then, the angle  $ACD$  being equal to the angle  $ADC$ , and the angle  $BCD$  to the angle  $BDC$ , by equal additions, the sum of the two angles  $ACD$ ,  $BCD$ , is equal to the sum of the two  $ADC$ ,  $BDC$ , (ax. 2), that is, the whole angle  $ACB$  equal to the whole angle  $ADB$ .

Since then, the two sides  $AC$ ,  $CB$ , are equal to the two sides  $AD$ ,  $DB$ , each to each (by hyp.), and their contained angles  $ACB$ ,  $ADB$ , also equal, the two triangles  $ABC$ ,  $ABD$ , are identical (th. 1), and have the other angles equal, viz., the angle  $BAC$  to the angle  $BAD$ , and the angle  $ABC$  to the angle  $ABD$ . Q. E. D.

#### THEOREM VI.

THE Angles which one Line makes with another, on the Same Side of it, are together equal to Two Right Angles.

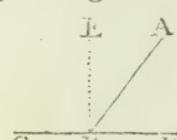
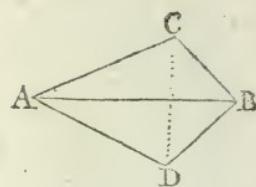
Let the line  $AB$  meet the line  $CD$ ; then will the two angles  $ABC$ ,  $ABD$ , taken together, be equal to two right angles.

For, first, when the two angles  $ABC$ ,  $ABD$ , are equal to each other, they are both of them right angles (def. 15).

But, when the angles are unequal, suppose  $BE$  drawn perpendicular to  $CD$ . Then, since the two angles  $EBC$ ,  $EBD$ , are right angles (def. 15), and the angle  $EBD$  is equal to the two angles  $EBA$ ,  $ABD$ , together (ax. 8), the three angles,  $EBC$ ,  $EBA$ , and  $ABD$ , are equal to two right angles.

But the two angles  $EBC$ ,  $EBA$ , are together equal to the angle  $ABC$  (ax. 8). Consequently the two angles  $ABC$ ,  $ABD$ , are also equal to two right angles. Q. E. D.

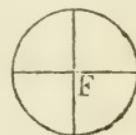
*Corol. 1.* Hence also, conversely, if the two angles  $ABC$ ,  $ABD$ , on both sides of the line  $AB$ , make up together two right angles, then  $CB$  and  $BD$  form one continued right line  $CD$ .



*Corol.* 2. Hence, all the angles which can be made, at any point  $B$ , by any number of lines, on the same side of the right line  $CD$ , are, when taken all together, equal to two right angles.

*Corol.* 3. And, as all the angles that can be made on the other side of the line  $CD$  are also equal to two right angles; therefore all the angles that can be made quite round a point  $B$ , by any number of lines, are equal to four right angles.

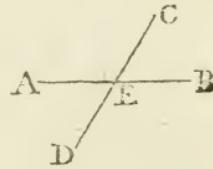
*Corol.* 4. Hence also the whole circumference of a circle, being the sum of the measures of all the angles that can be made about the centre  $F$  (def. 57), is the measure of four right angles. Consequently a semicircle, or  $180$  degrees, is the measure of two right angles; and a quadrant, or  $90$  degrees, the measure of one right angle.



### THEOREM VII.

If two Lines Intersect each other, the Opposite Angles will be equal.

Let the two lines  $AB$ ,  $CD$ , intersect in the point  $E$ ; then will the angle  $AEC$  be equal to the angle  $BED$ , and the angle  $AED$  equal to the angle  $CEB$ .



For, since the line  $CE$  meets the line  $AB$ , the two angles  $AEC$ ,  $BEC$ , taken together, are equal to two right angles (th. 6).

In like manner, the line  $BE$ , meeting the line  $CD$ , makes the two angles  $BEC$ ,  $BED$ , equal to two right angles.

Therefore the sum of the two angles  $AEC$ ,  $BEC$ , is equal to the sum of the two  $BEC$ ,  $BED$  (ax. 1).

And if the angle  $BEC$ , which is common, be taken away from both these, the remaining angle  $AEC$  will be equal to the remaining angle  $BED$  (ax. 3).

And in like manner it may be shewn, that the angle  $AED$  is equal to the opposite angle  $BEC$ .

### THEOREM VIII.

If One Side of a Triangle be produced, the Outward Angle will be Greater than either of the two Inward Opposite Angles.

Let

Let  $ABC$  be a triangle, having the side  $AB$  produced to  $D$ ; then will the outward angle  $CBD$  be greater than either of the inward opposite angles  $A$  or  $C$ .

For, conceive the side  $BC$  to be bisected in the point  $E$ , and draw the line  $AE$ , producing it till  $EF$  be equal to  $AE$ ; and join  $BF$ .

Then, since the two triangles  $AFC$ ,  $BFF$ , have the side  $AE =$  the side  $EF$ , and the side  $CE =$  the side  $BE$  (by suppos.) and the included or opposite angles at  $E$  also equal (th. 7.), therefore those two triangles are equal in all respects (th. 1), and have the angle  $c =$  the corresponding angle  $EBF$ . But the angle  $CBD$  is greater than the angle  $EBF$ ; consequently the said outward angle  $CBD$  is also greater than the angle  $c$ .

In like manner, if  $CB$  be produced to  $G$ , and  $AB$  be bisected, it may be shewn that the outward angle  $ABG$ , or its equal  $CBD$ , is greater than the other angle  $A$ .

#### THEOREM IX.

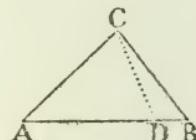
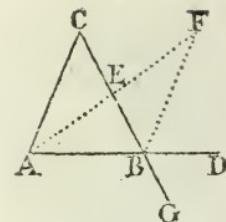
**THE** Greater Side, of every Triangle, is Opposite to the Greater Angle; and the Greater Angle opposite to the Greater Side.

Let  $ABC$  be a triangle, having the side  $AB$  greater than the side  $AC$ ; then will the angle  $ACB$ , opposite the greater side  $AB$ , be greater than the angle  $B$ , opposite the less side  $AC$ .

For, on the greater side  $AB$  take the part  $AD$  equal to the less side  $AC$ , and join  $CD$ . Then, since  $BCD$  is a triangle, the outward angle  $ADC$  is greater than the inward opposite angle  $B$  (th. 8.). But the angle  $ACD$  is equal to the said outward angle  $ADC$ , because  $AD$  is equal to  $AC$  (th. 3.). Consequently the angle  $ACD$  also is greater than the angle  $B$ . And since the angle  $ACD$  is only a part of  $ACB$ , much more must the whole angle  $ACB$  be greater than the angle  $B$ . Q. E. D.

Again, conversely, if the angle  $c$  be greater than the angle  $B$ , then will the side  $AB$ , opposite the former, be greater than the side  $AC$ , opposite the latter.

For, if  $AB$  be not greater than  $AC$ , it must be either equal to it, or less than it. But it cannot be equal, for then



then the angle  $c$  would be equal to the angle  $b$  (th. 3), which it is not, by the supposition. Neither can it be less, for then the angle  $c$  would be less than the angle  $b$ , by the former part of this; which is also contrary to the supposition. The side  $AB$ , then, being neither equal to  $AC$ , nor less than it, must necessarily be greater. Q. E. D.

## THEOREM X.

THE Sum of any Two Sides of a Triangle, is Greater than the Third Side.

Let  $ABC$  be a triangle; then will the sum of any two of its sides be greater than the third side, as for instance,  $AC + CB$  greater than  $AB$ .

For, produce  $AC$  till  $CD$  be equal to  $CB$ , or  $AD$  equal to the sum of the two  $AC + CB$ ; and join  $BD$ :—Then, because  $CD$  is equal to  $CB$  (by constr.), the angle  $D$  is equal to the angle  $CBD$  (th. 3). But the angle  $ABD$  is greater than the angle  $CBD$ , consequently it must also be greater than the angle  $D$ . And, since the greater side of any triangle is opposite to the greater angle (th. 9), the side  $AD$  (of the triangle  $ABD$ ) is greater than the side  $AB$ . But  $AD$  is equal to  $AC$  and  $CD$ , or  $AC$  and  $CB$ , taken together (by constr.); therefore  $AC + CB$  is also greater than  $AB$ . Q. E. D.

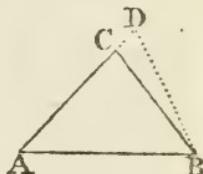
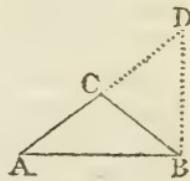
*Corol.* The shortest distance between two points, is a single right line drawn from the one point to the other.

## THEOREM XI.

THE Difference of any Two Sides of a Triangle is Less than the Third Side.

Let  $ABC$  be a triangle; then will the difference of any two sides, as  $AB - AC$ , be less than the third side  $BC$ .

For, produce the less side  $AC$  to  $D$ , till  $AD$  be equal to the greater side  $AB$ , so that  $CD$  may be the difference of the two sides  $AB - AC$ ; and join  $BD$ . Then, because  $AD$  is equal to  $AB$  (by constr.), the opposite angles  $D$  and  $ABD$  are equal (th. 3). But the angle  $CBD$  is less than the angle  $ABD$ , and consequently also less than the equal angle  $D$ . And since the greater side of any triangle is



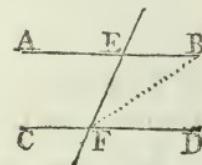
is opposite to the greater angle (th. 9), the side  $CD$  (of the triangle  $BCD$ ) is less than the side  $BC$ . Q. E. D.

## THEOREM XII.

IF a Line Intersect two Parallel Lines, it will make the Alternate Angles Equal to each other.

Let the line  $EF$  cut the two parallel lines  $AB$ ,  $CD$ ; then will the angle  $AEF$  be equal to the alternate angle  $EFD$ .

For if they are not equal, one of them must be greater than the other; let it be  $EFD$  for instance which is the greater, if possible; and conceive the line  $FB$  to be drawn, cutting off the part or angle  $EFB$  equal to the angle  $AEF$ , and meeting the line  $AB$  in the point  $B$ .



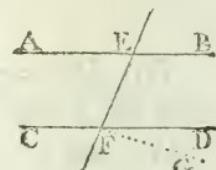
Then, since the outward angle  $AEF$ , of the triangle  $BEF$ , is greater than the inward opposite angle  $EFB$  (th. 8); and since these two angles also are equal (by the constr.) it follows, that these angles are both equal and unequal at the same time: which is impossible. Therefore the angle  $EFD$  is not unequal to the alternate angle  $AEF$ , that is, they are equal to each other. Q. E. D.

*Corol.* Right lines which are perpendicular to one, of two parallel lines, are also perpendicular to the other.

## THEOREM XIII.

IF a Line, Cutting Two other Lines, make the Alternate Angles Equal to each other, those two Lines will be Parallel.

Let the line  $EF$ , cutting the two lines  $AB$ ,  $CD$ , make the alternate angles  $AEF$ ,  $EFD$ , equal to each other; then will  $AB$  be parallel to  $CD$ .



For if they be not parallel, let some other line, as  $FG$ , be parallel to  $AB$ . Then, because of these parallels, the angle  $AEF$  is equal to the alternate angle  $EFG$  (th. 12). But the angle  $AEF$  is equal to the angle  $EFD$  (by hyp.) Therefore the angle  $EFD$  is equal to the angle  $EFG$  (ax. 1), that is, a part is equal to the whole, which is impossible. Therefore no line but  $CD$  can be parallel to  $AB$ . Q. E. D.

*Corol.* Those lines which are perpendicular to the same line, are parallel to each other.

## THEOREM XIV.

If a Line cut two Parallel Lines; the Outward Angle will be Equal to the Inward Opposite one, on the Same Side; and the two Inward Angles, on the Same Side, will be equal to Two Right Angles.

Let the line  $EF$  cut the two parallel lines  $AB$ ,  $CD$ ; then will the outward angle  $EGB$  be equal to the inward opposite angle  $GHD$ , on the same side of the line  $EF$ ; and the two inward angles  $BGH$ ,  $GHD$ , taken together, will be equal to two right angles.

For, since the two lines  $AB$ ,  $CD$ , are parallel, the angle  $AGH$  is equal to the alternate angle  $GHD$ , (th. 12). But the angle  $AGH$  is equal to the opposite angle  $EGB$  (th. 7). Therefore the angle  $EGB$  is also equal to the angle  $GHD$  (ax. 1). Q. E. D.

Again, because the two adjacent angles  $EGB$ ,  $BGH$ , are together equal to two right angles (th. 6); of which the angle  $EGB$  has been shewn to be equal to the angle  $GHD$ ; therefore the two angles  $BGH$ ,  $GHD$ , taken together, are also equal to two right angles.

*Corol.* 1. And, conversely, if one line meeting two other lines, make the angles on the same side of it equal, those two lines are parallels.

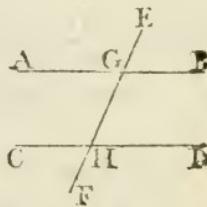
*Corol.* 2. If a line, cutting two other lines, make the sum of the two inward angles, on the same side, less than two right angles, those two lines will not be parallel, but will meet each other when produced.

## THEOREM XV.

THOSE Lines which are Parallel to the Same Line, are Parallel to each other.

Let the lines  $AB$ ,  $CD$ , be each of them parallel to the line  $EF$ ; then shall the lines  $AB$ ,  $CD$ , be parallel to each other.

For, let the line  $GI$  be perpendicular to  $EF$ . Then will this line be also perpendicular to both the lines  $AB$ ,  $CD$  (corol. th. 12), and consequently the two lines  $AB$ ,  $CD$ , are parallels (corol. th. 13).

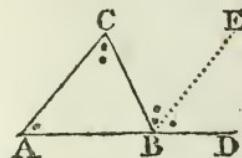


Q. E. D.

## THEOREM XVI.

If one Side of a Triangle be produced, the Outward Angle will be equal to both the Inward Opposite Angles taken together.

Let the side  $AB$ , of the triangle  $ABC$ , be produced to  $D$ ; then will the outward angle  $CBD$  be equal to the sum of the two inward opposite angles  $A$  and  $c$ .



For, conceive  $BE$  to be drawn parallel to the side  $AC$  of the triangle.

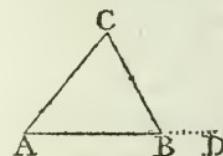
Then  $BC$ , meeting the two parallels  $AC$ ,  $BE$ , makes the alternate angles  $c$  and  $CBE$  equal (th. 12). And  $AD$ , cutting the same two parallels  $AC$ ,  $BE$ , makes the inward and outward angles on the same side,  $A$  and  $EBC$ , equal to each other (th. 14). Therefore, by equal additions, the sum of the two angles  $A$  and  $c$ , is equal to the sum of the two  $CBE$  and  $EBC$ , that is, to the whole angle  $CBD$  (by ax. 2). Q. E. D.

## THEOREM XVII.

In any Triangle, the Sum of all the Three Angles is equal to Two Right Angles.

Let  $ABC$  be any plane triangle; then the sum of the three angles  $A + B + C$  is equal to two right angles.

For, let the side  $AB$  be produced to  $D$ . Then the outward angle  $CBD$  is equal to the sum of the two inward opposite angles  $A + c$  (th. 16). To each of these equals add the inward angle  $B$ , then will the sum of the three inward angles  $A + B + c$  be equal to the sum of the two adjacent angles  $ABC + CBD$  (ax. 2). But the sum of these two last adjacent angles is equal to two right angles (th. 6). Therefore also the sum of the three angles of the triangle  $A + B + c$  is equal to two right angles (ax. 1). Q. E. D.



*Corol.* 1. If two angles in one triangle, be equal to two angles in another triangle, the third angles will also be equal (ax. 3), and the two triangles equiangular.

*Corol.* 2. If one angle in one triangle, be equal to one angle in another, the sums of the remaining angles will also be equal (ax. 3).

*Corol.* 3.

*Corol.* 3. If one angle of a triangle be right, the sum of the other two will also be equal to a right angle, and each of them singly will be acute, or less than a right angle.

*Corol.* 4. The two least angles of every triangle are acute, or each less than a right angle.

## THEOREM XVIII.

IN any quadrangle, the Sum of all the Four Inward Angles, is equal to Four Right Angles.

Let  $ABCD$  be a quadrangle; then the sum of the four inward angles,  $A + B + C + D$  is equal to four right angles.

Let the diagonal  $AC$  be drawn, dividing the quadrangle into two triangles,  $ABC$ ,  $ADC$ . Then, because the sum of the three angles of each of these triangles is equal to two right angles (th. 17); it follows, that the sum of all the angles of both triangles, which make up the four angles of the quadrangle, must be equal to four right angles (ax. 2).

Q. E. D.

*Corol.* 1. Hence, if three of the angles be right ones, the fourth will also be a right angle.

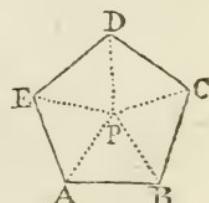
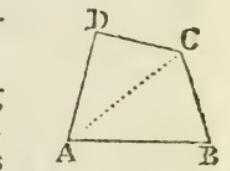
*Corol.* 2. Also, if the sum of two of the four angles be equal to two right angles, the sum of the remaining two will likewise be equal to two right angles.

## THEOREM XIX.

IN any plane figure, the Sum of all the Inward Angles, taken together, is equal to Twice as many Right Angles, wanting four, as the Figure has Sides.

Let  $ABCDE$  be any plane figure; then the sum of all its inward angles,  $A + B + C + D + E$ , is equal to twice as many right angles, wanting four, as the figure has sides.

For, from any point  $P$ , within it, draw lines  $PA$ ,  $PB$ ,  $PC$ , &c., to all the angles, dividing the polygon into as many triangles as it has sides. Now the sum of the three angles of each of these triangles, is equal to two right angles (th. 17); therefore the sum of the angles of all the triangles is equal to twice as many right angles as the figure has sides. But the sum of all the angles about the point  $P$ , which are so



many of the angles of the triangles, but no part of the inward angles of the polygon, is equal to four right angles (corol 3, th. 6), and must be deducted out of the former sum. Hence it follows that the sum of all the inward angles of the polygon alone,  $A + B + C + D + E$ , is equal to twice as many right angles as the figure has sides, wanting the said four right angles. Q. E. D.

## THEOREM XX.

If every Side of any right-lined Figure be produced out, the Sum of all the Outward Angles thereby made, will be equal to Four Right Angles.

Let  $A, B, C, \&c.$ , be the outward angles of any polygon, made by producing all the sides, then will the sum  $A + B + C + D + E$ , of all those outward angles, be equal to four right angles.

For every one of these outward angles, together with its adjacent inward angle, make up two right angles, as  $A + a$  equal to two right angles, being the two angles made by one line meeting another (th. 6). And there being as many outward, or inward angles, as the figure has sides. Therefore the sum of all the inward and outward angles, is equal to twice as many right angles as the figure has sides. But the sum of all the inward angles, with four right angles, is equal to twice as many right angles as the figure has sides (th. 19). Therefore the sum of all the inward and all the outward angles, is equal to the sum of all the inward angles and four right angles (by ax. 1). From each of these take away all the inward angles, and there remains all the outward angles equal to four right angles (by ax. 3).

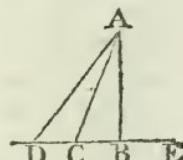
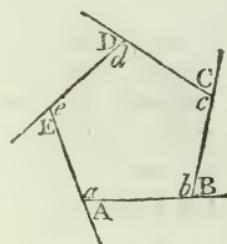
## THEOREM XXI.

A PERPENDICULAR is the Shortest Line that can be drawn from a Given Point to an Indefinite Line. And, of any other Lines drawn from the same Point, those that are Nearest the Perpendicular, are Less than those More Remote.

If  $AB, AC, AD, \&c.$ , be lines drawn from the given point  $A$ , to the indefinite line  $DE$ , of which  $AB$  is perpendicular. Then shall the perpendicular  $AB$  be less than  $AC$ , and  $AC$  less than  $AD$ , &c.

For, the angle  $B$  being a right one, the

angle



angle  $c$  is acute (by cor. 3, th. 17), and therefore less than the angle  $b$ . But the less angle of a triangle is subtended by the less side (th. 9). Therefore the side  $AB$  is less than the side  $AC$ .

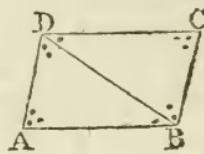
Again, the angle  $ACB$  being acute, as before, the adjacent angle  $ACD$  will be obtuse (by th. 6). But the angle  $d$  is acute (corol. 3, th. 17). Therefore the angle  $d$  is less than the angle  $c$ . And, since the less side is opposite to the less angle, therefore the side  $AC$  is less than the side  $AD$ . Q. E. D.

*Corol.* A perpendicular is the least distance of a given point from a line.

## THEOREM XXII.

THE Opposite Sides and Angles of any Parallelogram are equal to each other; and the Diagonal divides it into two Equal Parts.

Let  $ABCD$  be a parallelogram, of which the diagonal is  $BD$ ; then will its opposite sides and angles be equal to each other, and the diagonal  $BD$  will divide it into two equal parts, or triangles.



For, since the sides  $AB$  and  $DC$ , are parallel, as also the sides  $AD$  and  $BC$  (defin. 32), and the line  $BD$  meets them; therefore the alternate angles are equal (th. 12), namely, the angle  $ABD$  to the angle  $CDB$ , and the angle  $ADB$  to the angle  $CBD$ . Hence the two triangles, having two angles in the one equal to two angles in the other, have also their third angles equal (cor. 1, th. 17), namely, the angle  $A$  equal to the angle  $c$ , which are two of the opposite angles of the parallelogram.

Also, if to the equal angles  $ABD$ ,  $CDB$ , be added the equal angles  $CBD$ ,  $ADB$ , the wholes will be equal (ax. 2), namely, the whole angle  $ABC$  to the whole  $ADC$ , which are the other two opposite angles of the parallelogram.

Q. E. D.

Again, since the two triangles are mutually equiangular, and have a side in each equal, viz. the common side  $BD$ ; therefore the two triangles are identical (th. 2), or equal in all respects, namely, the side  $AB$  equal to the opposite side  $DC$ , and  $AD$  equal to the opposite side  $BC$ , and the whole triangle  $ABD$  equal to the whole triangle  $BCD$ . Q. E. D.

*Corol.* 1. Hence, if one angle of a parallelogram be a right angle, all the other three will also be right angles, and the parallelogram a rectangle.

*Corol.* 2. Hence also, the sum of any two adjacent angles of a parallelogram is equal to two right angles.

### THEOREM XXIII.

EVERY Quadrilateral whose Opposite Sides are Equal, is a Parallelogram.

Let  $ABCD$  be a quadrangle, having the opposite sides equal, namely, the side  $AB$  equal to  $DC$ , and  $AD$  equal to  $BC$ ; then shall these equal sides be also parallel, and the figure a parallelogram.

For, let the diagonal  $BD$  be drawn. Then, the triangles  $ABD$ ,  $CBD$ , being mutually equilateral (by hyp.), they are also mutually equiangular (th. 5), or have their corresponding angles equal; consequently the opposite sides are parallel (th. 13); viz. the side  $AB$  parallel to  $DC$ , and  $AD$  parallel to  $BC$ , and the figure is a parallelogram. Q. E. D.

### THEOREM XXIV.

THOSE Lines which join the Corresponding Extremes of two Equal and Parallel Lines, are themselves Equal and Parallel.

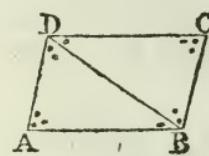
Let  $AB$ ,  $DC$ , be two equal and parallel lines; then will the lines  $AD$ ,  $BC$ , which join their extremes, be also equal and parallel. [See the fig. above.]

For, draw the diagonal  $BD$ . Then, because  $AB$  and  $DC$  are parallel (by hyp.), the angle  $ABD$  is equal to the alternate angle  $BDC$  (th. 12). Hence then, the two triangles having two sides and the contained angles equal, viz. the side  $AB$  equal to the side  $DC$ , and the side  $BD$  common, and the contained angle  $ABD$  equal to the contained angle  $BDC$ , they will have the remaining sides and angles also respectively equal (th. 1); consequently  $AD$  equal to  $BC$ , and also parallel to it (th. 12). Q. E. D.

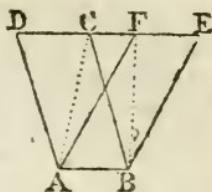
### THEOREM XXV.

PARALLELOGRAMS, or Triangles, standing on the Same Base, and between the Same Parallels, are equal to each other.

Let



Let  $ABCD$ ,  $ABEF$ , be two parallelograms, and  $ABC$ ,  $AEF$ , two triangles, standing on the same base  $AB$ , and between the same parallels  $AB$ ,  $DE$ ; then will the parallelogram  $ABCD$  be equal to the parallelogram  $ABEF$ , and the triangle  $ABC$  equal to the triangle  $ABF$ .



For, since the line  $DE$  cuts the two parallels  $AF$ ,  $BE$ , and the two  $AD$ ,  $BC$ , it makes the angle  $E$  equal to the angle  $AFD$ , and the angle  $D$  equal to the angle  $BCE$  (th. 14); the two triangles  $ADF$ ,  $BCE$ , are therefore equiangular (cor. 1, th. 17); and having the two corresponding sides,  $AD$ ,  $BC$ , equal (th. 22), being opposite sides of a parallelogram, these two triangles are identical, or equal in all respects (th. 2). If each of these equal triangles then be taken from the whole space  $ABED$ , there will remain the parallelogram  $ABEF$  in the one case, equal to the parallelogram  $ABCD$  in the other (by ax. 3).

Also the triangles  $ABC$ ,  $ABF$ , on the same base  $AB$ , and between the same parallels, are equal, being the halves of the said equal parallelograms (th. 22). Q. E. D.

*Corol.* 1. Parallelograms, or triangles, having the same base and altitude, are equal. For the altitude is the same as the perpendicular or distance between the two parallels, which is every where equal, by the definition of parallels.

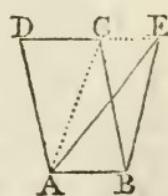
*Corol.* 2 Parallelograms, or triangles, having equal bases and altitudes, are equal. For, if the one figure be applied with its base upon the other, the bases will coincide or be the same, because they are equal; and so the two figures, having the same base and altitude, are equal.

#### THEOREM XXVI.

IF a Parallelogram and a Triangle stand on the Same Base, and between the Same Parallels, the Parallelogram will be Double the Triangle, or the Triangle Half the Parallelogram.

Let  $ABCD$  be a parallelogram, and  $ABE$  a triangle, on the same base  $AB$ , and between the same parallels  $AB$ ,  $DE$ ; then will the parallelogram  $ABCD$  be double the triangle  $ABE$ , or the triangle half the parallelogram.

For, draw the diagonal  $AC$  of the parallelogram, dividing it into two equal parts (th. 22). Then because the triangles  $ABC$ ,



$ABE$ ,

$\triangle ABE$ , on the same base, and between the same parallels, are equal (th. 25); and because the triangle  $\triangle ABC$  is half the parallelogram  $ABCD$  (th. 22), the other equal triangle  $\triangle ABE$  is also equal to half the same parallelogram  $ABCD$ . Q. E. D.

*Corol.* 1. A triangle is equal to half a parallelogram of the same base and altitude, because the altitude is the perpendicular distance between the parallels, which is every where equal, by the definition of parallels.

*Corol.* 2. If the base of a parallelogram be half that of a triangle, of the same altitude, or the base of the triangle be double that of the parallelogram, the two figures will be equal to each other.

#### THEOREM XXVII.

RECTANGLES that are contained under Equal Lines, are Equal to each other.

Let  $BD, FH$  be two rectangles, having the sides  $AB, BC$ , equal to the sides  $EF, FG$ , each to each; then will the rectangle  $BD$  be equal to the rectangle  $FH$ .

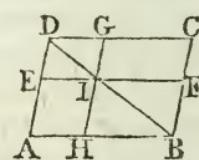
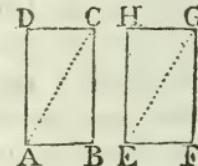
For, draw the two diagonals  $AC, EG$ , dividing the two parallelograms each into two equal parts. Now the two triangles  $\triangle ABC, \triangle EFG$ , are equal to each other (th. 1), because they have the two sides  $AB, BC$ , and the contained angle  $B$ , equal to the two sides  $EF, FG$ , and the contained angle  $F$  (by hyp.). But these equal triangles are the halves of the respective rectangles. And because the halves, or the triangles, are equal, the wholes, or the rectangles  $DB, HF$ , are also equal (by ax. 6). Q. E. D.

*Corol.* The squares on equal lines, are also equal; for every square is a species of rectangle.

#### THEOREM XXVIII.

THE Complements of the Parallelograms, which are about the Diagonal of any Parallelogram, are equal to each other.

Let  $AC$  be a parallelogram,  $BD$  a diagonal,  $EIF$  parallel to  $AB$  or  $DC$ , and  $GIH$  parallel to  $AD$  or  $BC$ , making  $AI$ ,  $IC$  complements to the parallelograms  $EG, HF$ , which are about the diagonal  $DB$ : then will the complement  $AI$  be equal to the complement  $IC$ .



For, since the diagonal  $DB$  bisects the three parallelograms  $AC$ ,  $EG$ ,  $HF$  (th. 22); therefore, the whole triangle  $DAB$  being equal to the whole triangle  $DCB$ , and the parts  $DEI$ ,  $IHB$ , respectively equal to the parts  $DGI$ ,  $IFB$ , the remaining parts  $AI$ ,  $IC$ , must also be equal (by ax. 3). Q. E. D.

## THEOREM XXIX.

A TRAPEZOID, or Trapezium having two Sides Parallel, is equal to Half a Parallelogram, whose Base is the Sum of those two Sides, and its Altitude the Perpendicular Distance between them.

Let  $ABCD$  be the trapezoid, having its two sides  $AB$ ,  $DC$ , parallel; and in  $AB$  produced take  $BE$  equal to  $DC$ , so that  $AE$  may be the sum of the two parallel sides; produce  $DC$  also, and let  $EF$ ,  $GC$ ,  $BH$ , be all three parallel to  $AD$ . Then is  $AF$  a parallelogram of the same altitude with the trapezoid  $ABCD$ , having its base  $AE$  equal to the sum of the parallel sides of the trapezoid; and it is to be proved that the trapezoid  $ABCD$  is equal to half the parallelogram  $AF$ .

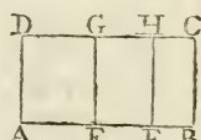
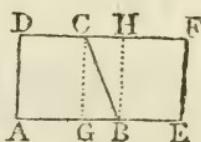
Now, since triangles, or parallelograms, of equal bases and altitude, are equal (corol. 2, th. 25), the parallelogram  $DG$  is equal to the parallelogram  $HE$ , and the triangle  $CGB$  equal to the triangle  $CHB$ ; consequently the line  $BC$  bisects, or equally divides, the parallelogram  $AF$ , and  $ABCD$  is the half of it. Q. E. D.

## THEOREM XXX.

THE Sum of all the Rectangles contained under one Whole Line, and the several Parts of another Line, any how divided, is Equal to the Rectangle contained under the Two Whole Lines.

Let  $AD$  be the one line, and  $AB$  the other line, divided into the parts  $AE$ ,  $EF$ ,  $FB$ ; then shall the rectangle contained by  $AD$  and  $AB$ , be equal to the sum of the rectangles of  $AD$  and  $AE$ ,  $AD$  and  $EF$ , and  $AD$  and  $FB$ : thus expressed,  $AD \cdot AB = AD \cdot AE + AD \cdot EF + AD \cdot FB$ .

For, make the rectangle  $AC$  of the two whole lines  $AD$ ,  $AB$ ; and draw  $EG$ ,  $FH$ , perpendicular to  $AB$ , or parallel to  $AD$ , to which they are equal (th. 22). Then the whole rectangle  $AC$  is made up of all the other rectangles  $AG$ ,



**EH, FC.** But these rectangles are contained by  $AD$  and  $AE$ ,  $EG$  and  $EF$ ,  $FH$  and  $FB$ ; which are equal to the rectangles of  $AD$  and  $AE$ ,  $AD$  and  $EF$ ,  $AD$  and  $FB$ , because  $AD$  is equal to each of the two,  $EG$ ,  $FH$ .

Therefore the rectangle  $AD \cdot AB$  is equal to the sum of all the other rectangles  $AD \cdot AE$ ,  $AD \cdot EF$ ,  $AD \cdot FB$ .

*Corol.* If a right line be divided into any two parts; the square on the whole line, is equal to both the rectangles of the whole line and each of the parts.

### THEOREM XXXI.

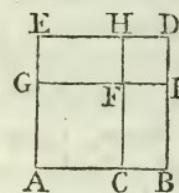
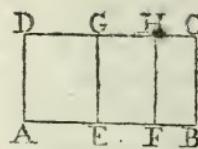
THE Square of the Sum of two Lines, is greater than the Sum of their Squares, by Twice the Rectangle of the said Lines. Or, the Square of a whole Line, is equal to the Squares of its two Parts, together with Twice the Rectangle of those Parts.

Let the line  $AB$  be the sum of any two lines  $AC$ ,  $CB$ : then will the square of  $AB$  be equal to the squares of  $AC$ ,  $CB$ , together with twice the rectangle of  $AC \cdot CB$ . That is,  $AB^2 = AC^2 + CB^2 + 2AC \cdot CB$ .

For, let  $ABDE$  be the square on the sum or whole line  $AB$ , and  $ACFG$  the square on the part  $AC$ . Produce  $CF$  and  $GF$  to the other sides at  $H$  and  $I$ .

From the lines  $CH$ ,  $GI$ , which are equal, being each equal to the sides of the square  $AB$  or  $BD$  (th. 22), take the parts  $CF$ ,  $GF$ ; which are equal also, being the sides of the square  $AF$ , and there remains  $FH$  equal to  $FI$ , which are also equal to  $DH$ ,  $DI$ , being the opposite sides of a parallelogram. Hence the figure  $HI$  is equilateral; and it has all its angles right ones (corol. 1, th. 22); it is therefore a square on the line  $FI$ , or the square of its equal  $CB$ . Also the figures  $EF$ ,  $FB$ , are equal to two rectangles under  $AC$  and  $CB$ , because  $GF$  is equal to  $AC$ , and  $FH$  or  $FI$  equal to  $CB$ . But the whole square  $AD$  is made up of the four figures, viz the two squares  $AF$ ,  $FD$ , and the two equal rectangles  $EF$ ,  $FB$ . That is, the square of  $AB$  is equal to the squares of  $AC$ ,  $CB$ , together with twice the rectangle of  $AC$ ,  $CB$ .

*Corol.* Hence, if a line be divided into two equal parts; the square of the whole line, will be equal to four times the square of half the line.



## THEOREM XXXII.

THE Square of the Difference of two Lines, is less than the Sum of their Squares, by Twice the Rectangle of the said Lines.

Let  $AC$ ,  $BC$ , be any two lines, and  $AB$  their difference : then will the square of  $AB$  be less than the squares of  $AC$ ,  $BC$ , by twice the rectangle of  $AC$  and  $BC$ . Or,  
 $AB^2 = AC^2 + BC^2 - 2AC \cdot BC$ .

For, let  $ABDE$  be the square on the difference  $AB$ , and  $ACFG$  the square on the line  $AC$ . Produce  $ED$  to  $H$ ; also produce  $DB$  and  $HC$ , and draw  $KI$ , making  $BI$  the square of the other line  $BC$ .

Now it is visible that the square  $AD$  is less than the two squares  $AF$ ,  $BI$ , by the two rectangles  $EF$ ,  $DI$ . But  $GF$  is equal to the one line  $AC$ , and  $GE$  or  $FH$  is equal to the other line  $BC$ ; consequently the rectangle  $EF$ , contained under  $EG$  and  $GF$ , is equal to the rectangle of  $AC$  and  $BC$ .

Again,  $FH$  being equal to  $Ci$  or  $BC$  or  $DH$ , by adding the common part  $HC$ , the whole  $Hi$  will be equal to the whole  $FC$  or equal to  $AC$ ; and consequently the figure  $DI$  is equal to the rectangle contained by  $AC$  and  $BC$ .

Hence the two figures  $EF$ ,  $DI$ , are two rectangles of the two lines  $AC$ ,  $BC$ ; and consequently the square of  $AB$  is less than the squares of  $AC$ ,  $BC$ , by twice the rectangle  $AC \cdot BC$ .

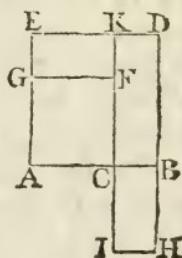
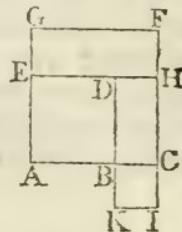
## THEOREM XXXIII.

THE Difference of the Squares of two Lines, is equal to the Rectangle under the Sum and Difference of the same Lines.

Let  $AB$ ,  $AC$ , be any two unequal lines ; then will the difference of the squares of  $AB$ ,  $AC$ , be equal to a rectangle under their sum and difference. That is,  $AE^2 - AC^2 = AB + AC \cdot AB - AC$ .

For, let  $ABDE$  be the square of  $AB$ , and  $ACFG$  the square of  $AC$ . Produce  $DB$  till  $BH$  be equal to  $AC$ ; draw  $HI$  parallel to  $AB$  or  $ED$ , and produce  $FC$  both ways to  $I$  and  $K$ .

Then the difference of the two squares  $AD$ ,  $AF$ , is evidently



dently the two rectangles  $EF$ ,  $KB$ . But the rectangles  $EF$ ,  $DI$ , are equal, being contained under equal lines; for  $EK$  and  $BH$  are each equal to  $AC$ , and  $GE$  is equal to  $CB$ , being each equal to the difference between  $AB$  and  $AC$ , or their equals  $AE$  and  $AG$ . Therefore the two  $EF$ ,  $KB$ , are equal to the two  $KB$ ,  $DI$ , or to the whole  $KH$ ; and consequently  $KH$  is equal to the difference of the squares  $AD$ ,  $AF$ . But  $KH$  is a rectangle contained under  $DH$ ; or the sum of  $AB$  and  $AC$ , and  $KD$ , or the difference of  $AB$  and  $AC$ . Therefore the difference of the squares of  $AB$ ,  $AC$ , is equal to the rectangle under their sum and difference. Q. E. D.

## THEOREM XXXIV.

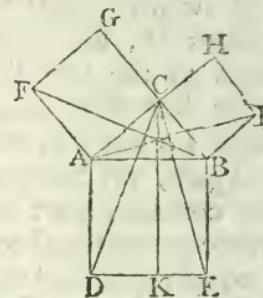
IN any Right-angled Triangle, the Square of the Hypotenuse, is equal to the Sum of the Squares of the other two Sides.

Let  $ABC$  be a right-angled triangle, having the right angle  $C$ ; then will the square of the hypotenuse  $AB$ , be equal to the sum of the squares of the other two sides  $AC$ ,  $CB$ . Or  $AB^2 = AC^2 + BC^2$ .

For, on  $AB$  describe the square  $AE$ , and on  $AC$ ,  $CB$ , the squares  $AG$ ,  $BH$ ; then draw  $CK$  parallel to  $AD$  or  $BE$ ; and join  $AI$ ,  $BF$ ,  $CD$ ,  $CE$ .

Now, because the line  $AC$  meets the two  $CG$ ,  $CB$ , so as to make two right angles, these two form one straight line  $GB$ . (corol 1, th 6). And because the angle  $FAC$  is equal to the angle  $DAB$ , being each a right angle, or the angle of a square; to each of these equals add the common angle  $EAC$ , so will the whole angle or sum  $FAB$ , be equal to the whole angle  $CAD$ . But the line  $FA$  is equal to the line  $AC$ , and the line  $AB$  to the line  $AD$ , being sides of the same square; so that the two sides  $FA$ ,  $AB$ , and their included angle  $FAB$ , are equal to the two sides  $CA$ ,  $AD$ , and the contained angle  $CAD$ , each to each; therefore the whole triangle  $AFB$  is equal to the whole triangle  $ACD$  (th. 1).

But the square  $AG$  is double the triangle  $AFB$ , on the same base  $FA$ , and between the same parallels  $FA$ ,  $GB$  (th. 26); in like manner, the parallelogram  $AK$  is double the triangle  $ACD$ , on the same base  $AD$ , and between the same parallels  $AD$ ,  $CK$ . And since the doubles of equal things, are equal (by ax. 6); therefore the square  $AG$  is equal to the parallelogram  $AK$ .



In like manner, the other square  $BH$  is proved equal to the other parallelogram  $BK$ . And consequently, the two squares  $AG$  and  $BH$  together, equal to the two parallelograms  $AK$  and  $BK$  together, or to the whole square  $AE$ . That is, the sum of the two squares on the two less sides, is equal to the square on the greatest side. Q. E. D.

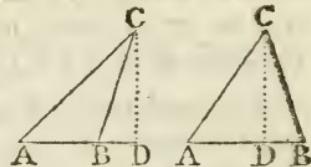
*Corol.* 1. Hence, the square of either of the two less sides, is equal to the difference of the squares of the hypotenuse and the other side (ax 3); or, equal to the rectangle contained under the sum and difference of the said hypotenuse and other side (th 33).

*Corol.* 2. Hence also, if two right-angled triangles have two sides of the one equal to two corresponding sides of the other; their third sides will, also be equal, and the triangles identical.

## THEOREM XXXV.

IN any Triangle, the Difference of the Squares of the two Sides, is Equal to the Difference of the Squares of the two Lines, or Distances, included between the Extremes of the Base and the Perpendicular.

Let  $ABC$  be any triangle, having  $CD$  perpendicular to  $AB$ ; then will the difference of the squares of  $AC$ ,  $BC$ , be equal to the difference of the squares of  $AD$ ,  $BD$ ; that is,  $AC^2 - BC^2 = AD^2 - BD^2$ .



For, since  $AC^2$  is equal to  $AD^2 + CD^2$  } (by th. 34);  
 and  $BC^2$  is equal to  $BD^2 + CD^2$  }  
 Theref. the difference between  $AC^2$  and  $BC^2$   
 is equal to the difference between  $AD^2 + CD^2$   
 and  $BD^2 + CD^2$   
 or equal to the difference between  $AD^2$  and  $BD^2$   
 by taking away the common square  $CD^2$ . Q. E. D.

*Corol.* The rectangle under the sum and difference of the two sides of any triangle, is equal to the rectangle under the sum and difference of the distances between the perpendicular and the two extremes of the base, or equal to the rectangle under the base and the difference or sum of the segments, according as the perpendicular falls within or without the triangle.

That

That is,  $\overline{AC} + \overline{BC} \cdot \overline{AC} - \overline{BC} = \overline{AD} + \overline{BD} \cdot \overline{AD} - \overline{BD}$

Or,  $\overline{AC} + \overline{BC} \cdot \overline{AC} - \overline{BC} = \overline{AB} \cdot \overline{AD} - \overline{BD}$  in the 2d figure.

And  $\overline{AC} + \overline{BC} \cdot \overline{AC} - \overline{BC} = \overline{AB} \cdot \overline{AD} + \overline{BD}$  in the 1st figure.

### THEOREM XXXVI.

IN any Obtuse-angled Triangle, the Square of the Side subtending the Obtuse Angle, is Greater than the Sum of the Squares of the other two Sides, by Twice the Rectangle of the Base and the Distance of the Perpendicular from the Obtuse Angle.

Let  $ABC$  be a triangle, obtuse angled at  $B$ , and  $CD$  perpendicular to  $AB$ ; then will the square of  $AC$  be greater than the squares of  $AB$ ,  $BC$ , by twice the rectangle of  $AB$ ,  $BD$ . That is,  $AC^2 = AB^2 + BC^2 + 2AB \cdot BD$ . See the 1st fig. above, or below.

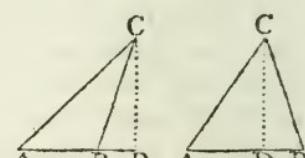
For, since the square of the whole line  $AD$  is equal to the squares of the parts  $AB$ ,  $BD$ , with twice the rectangle of the same parts  $AB$ ,  $BD$  (th. 31): if to each of these equals there be added the square of  $CD$ , then the squares of  $AD$ ,  $CD$ , will be equal to the squares of  $AB$ ,  $BD$ ,  $CD$ , with twice the rectangle of  $AB$ ,  $BD$  (by ax. 2).

But the squares of  $AD$ ,  $CD$ , are equal to the square of  $AC$ ; and the squares of  $BD$ ,  $CD$ , equal to the square of  $BC$  (th. 34); therefore the square of  $AC$  is equal to the squares of  $AB$ ,  $BC$ , together with twice the rectangle of  $AB$ ,  $BD$ . Q. E. D.

### THEOREM XXXVII.

IN any Triangle, the Square of the Side subtending an Acute Angle, is Less than the Squares of the Base and the other Side, by Twice the Rectangle of the Base and the Distance of the Perpendicular from the Acute Angle.

Let  $ABC$  be a triangle, having the angle  $A$  acute, and  $CD$  perpendicular to  $AB$ ; then will the square of  $BC$ , be less than the squares of  $AB$ ,  $AC$ , by twice the rectangle of  $AB$ ,  $AD$ . That is,  $BC^2 = AB^2 + AC^2 - 2AB \cdot AD$ .



For,

For, in fig. 1,  $AC^2$  is =  $BC^2 + AB^2 + 2AB \cdot BD$  (th. 36).  
 To each of these equals add the square of  $AB$ ,  
 then is  $AB^2 + AC^2 = BC^2 + 2AB^2 + 2AB \cdot ED$  (ax. 2),  
 or =  $BC^2 + 2AB \cdot AD$  (th. 30).

Q. E. D.

Again, in fig. 2,  $AC^2$  is =  $AD^2 + DC^2$  (th. 34).

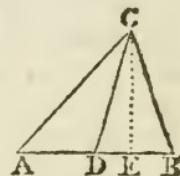
And  $AB^2 = AD^2 + DB^2 + 2AD \cdot DB$  (th. 31).

Theref.  $AB^2 + AC^2 = BD^2 + DC^2 + 2AD^2 + 2AD \cdot DB$  (ax. 2),  
 or =  $BC^2 + 2AD^2 + 2AD \cdot DB$  (th. 34),  
 or =  $BC^2 + 2AB \cdot AD$  (th. 30). Q. E. D.

## THEOREM XXXVIII.

IN any Triangle, the Double of the Square of a Line drawn from the Vertex to the Middle of the Base, together with Double the Square of the Half Base, is Equal to the Sum of the Squares of the other Two Sides.

Let  $ABC$  be a triangle, and  $CD$  the line drawn from the vertex to the middle of the base  $AB$ , bisecting it into the two equal parts  $AD$ ,  $DB$ ; then will the sum of the squares of  $AC$ ,  $CB$ , be equal to twice the sum of the squares of  $CD$ ,  $BD$ ; or  $AC^2 + CB^2 = 2CD^2 + 2DB^2$ .

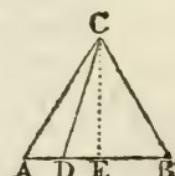


For, let  $CE$  be perpendicular to the base  $AB$ . Then, since (by th. 36)  $AC^2$  exceeds the sum of the two squares  $AD^2$  and  $CD^2$  (or  $BD^2$  and  $CD^2$ ) by the double rectangle  $2AD \cdot DE$  (or  $2BD \cdot DE$ ); and since (by th. 37)  $BC^2$  is less than the same sum by the said double rectangle; it is manifest that both  $AC^2$  and  $BC^2$  together, must be equal to that sum twice taken; the excess on the one part making up the defect on the other. Q. E. D.

## THEOREM XXXIX.

IN an Isosceles Triangle, the Square of a Line drawn from the Vertex to any Point in the Base, together with the Rectangle of the Segments of the Base, is Equal to the Square of one of the Equal Sides of the Triangle.

Let  $ABC$  be the isosceles triangle, and  $CD$  a line drawn from the vertex to any point  $D$  in the base: then will the square of  $AC$  be equal to the square of  $CD$  together with the rectangle of  $AD$  and  $DB$ . That is,  $AC^2 = CD^2 + AD \cdot DB$ .



For,

For, let  $CE$  bisect the vertical angle: then will it also bisect the base  $AB$  perpendicularly, making  $AE = EB$  (cor. 1, h. 3).

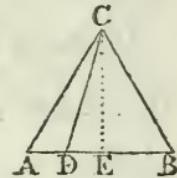
But, in the triangle  $ACD$ , obtuse angled at  $D$ , the square  $AC^2$  is  $= CD^2 + AD^2 + 2AD \cdot DE$  (th. 36),

$$\text{or } = CD^2 + AD \cdot \underline{AD} + \underline{2DE} \text{ (th. 30),}$$

$$\text{or } = CD^2 + AD \cdot \underline{AE} + \underline{DE},$$

$$\text{or } = CD^2 + AD \cdot \underline{BE} + \underline{DE},$$

$$\text{or } = CD^2 + AD \cdot DB.$$



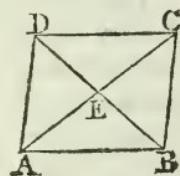
Q. E. D.

#### THEOREM XL.

IN any Parallelogram, the two Diagonals Bisection each other, and the Sum of their Squares is equal to the Sum of the Squares of all the Four Sides of the Parallelogram.

Let  $ABCD$  be a parallelogram, whose diagonals intersect each other in  $E$ : then will  $AE$  be equal to  $EC$ , and  $BE$  to  $ED$ ; and the sum of the squares of  $AC$ ,  $BD$ , will be equal to the sum of the squares of  $AB$ ,  $BC$ ,  $CD$ ,  $DA$ . That is,

$$AE = EC, \text{ and } BE = ED, \\ \text{and } AC^2 + BD^2 = AB^2 + BC^2 + CD^2 + DA^2.$$



For, the triangles  $AEB$ ,  $DEC$ , are equiangular, because they have the opposite angles at  $E$  equal (th. 7), and the two lines  $AC$ ,  $BD$ , meeting the parallels  $AB$ ,  $DC$ , make the angle  $BAE$  equal to the angle  $DCE$ , and the angle  $ABE$  equal to the angle  $CDE$ , and the side  $AB$  equal to the side  $DC$  (th. 22); therefore these two triangles are identical, and have their corresponding sides equal (th. 2), viz.  $AE = EC$ ,  $BE = ED$ .

Again, since  $AC$  is bisected in  $E$ , the sum of the squares  $AD^2 + DC^2 = 2AE^2 + 2DE^2$  (th. 38).

In like manner,  $AB^2 + BC^2 = 2AE^2 + 2BE^2$  or  $2DE^2$ . Theref.  $AB^2 + BC^2 + CD^2 + DA^2 = 4AE^2 + 4DE^2$  (ax. 2).

But, because the square of a whole line is equal to four times the square of half the line (cor. th. 31), that is,  $AC^2 = 4AE^2$ , and  $BD^2 = 4DE^2$ .

Theref.  $AB^2 + BC^2 + CD^2 + DA^2 = AC^2 + BD^2$  (ax. 1).

Q. E. D.

## THEOREM XLI.

If a Right Line, drawn through or from the Centre of a Circle, Bise<sup>c</sup>t a Chord, it will be Perpendicular to it; or if it be Perpendicular to the Chord, it will Bisect both the Chord and the Arc of the Chord.

Let  $AB$  be any chord in a circle, and  $CD$  a line drawn from the centre  $C$  to the chord. Then, if the chord be bisected in the point  $D$ ,  $CD$  will be perpendicular to  $AB$ .

For, draw the two radii  $CA$ ,  $CB$ . Then the two triangles  $ACD$ ,  $BCD$ , having  $CA$  equal to  $CB$  (def. 44),  $CD$  common, and  $AD$  equal to  $DB$  (by hyp.); have all the three sides of the one, equal to all the three sides of the other, and so have their angles also equal (th. 5). Hence then, the angle  $ADC$  being equal to the angle  $BDC$ , these angles are right angles, and the line  $CD$  is perpendicular to  $AB$  (def. 11).

Again, if  $CD$  be perpendicular to  $AB$ , then will the chord  $AB$  be bisected at the point  $D$ , or have  $AD$  equal to  $DB$ , and the arc  $AEB$  in the point  $E$ , or have  $AE$  equal  $EB$ .

For, having drawn  $CA$ ,  $CB$ , as before. Then, in the triangle  $ABC$ , because the side  $CA$  is equal to the side  $CB$ , their opposite angles  $A$  and  $B$  are also equal (th. 3). Hence then, in the two triangles  $ACD$ ,  $BCD$ , the angle  $A$  is equal to the angle  $B$ , and the angles at  $D$  are equal (def. 11); therefore their third angles are also equal (corol. 1, th. 17). And having the side  $CD$  common, they have also the side  $AD$  equal to the side  $DB$  (th. 2).

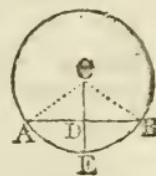
Also, since the angle  $ACE$  is equal to the angle  $BCE$ , the arc  $AE$ , which measures the former (def. 57), is equal to the arc  $BE$ , which measures the latter, since equal angles must have equal measures.

*Corol.* Hence a line bisecting any chord at right angles, passes through the centre of the circle.

## THEOREM XLII

If More than Two Equal Right Lines can be drawn from any Point within a Circle to the Circumference, that Point will be the Centre.

Let



Let  $ABC$  be a circle, and  $D$  a point within it; then if any three lines,  $DA$ ,  $DB$ ,  $DC$ , drawn from the point  $D$  to the circumference, be equal to each other, the point  $D$  will be the centre.

For, draw the chords  $AB$ ,  $BC$ , which let be bisected in the points  $E$ ,  $F$ , and join  $DE$ ,  $DF$ .

Then, the two triangles  $DAE$ ,  $DBE$ , have the side  $DA$  equal to the side  $DB$  by supposition, the side  $AE$  equal to the side  $EB$  by hypothesis, and the side  $DE$  common; therefore these two triangles are identical, and have the angles at  $E$  equal to each other (th. 5); consequently  $DE$  is perpendicular to the chord  $AB$  (def. 11), and therefore passes through the centre of the circle (corol. th. 41).

In like manner, it may be shewn that  $DF$  passes through the centre. Consequently the point  $D$  is the centre of the circle, and the three equal lines  $DA$ ,  $DB$ ,  $DC$ , are radii.

Q. E. D.

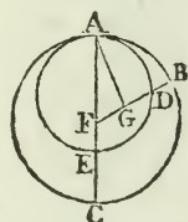
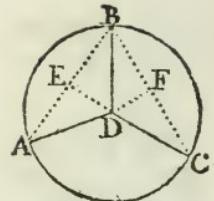
#### THEOREM XLIII.

If two Circles touch one another Internally, the Centres of the Circles and the Point of Contact will be all in the Same Right Line.

Let the two circles  $ABC$ ,  $ADE$ , touch one another internally in the point  $A$ ; then will the point  $A$  and the centres of these circles be all in the same right line.

For, let  $F$  be the centre of the circle  $ABC$ , through which draw the diameter  $AFC$ . Then, if the centre of the other circle can be out of this line  $AC$ , let it be supposed in some other point as  $G$ ; through which draw the line  $FG$  cutting the two circles in  $B$  and  $D$ .

Now, in the triangle  $AFG$ , the sum of the two sides  $FG$ ,  $GA$ , is greater than the third side  $AF$  (th. 10), or greater than its equal radius  $FB$ . From each of these take away the common part  $FG$ , and the remainder  $GA$  will be greater than the remainder  $GB$ . But the point  $G$  being supposed the centre of the inner circle, its two radii  $GA$ ,  $GD$ , are equal to one another; consequently  $GD$  will also be greater than  $GB$ . But  $ADE$  being the inner circle,  $GD$  is necessarily less



less than  $GB$ . So that  $GD$  is both greater and less than  $GB$ ; which is absurd. Consequently the centre  $G$  cannot be out of the line  $AFC$ . Q. E. D.

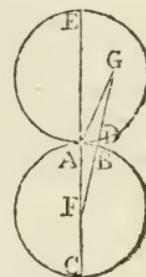
## THEOREM XLIV.

If two Circles Touch one another Externally, the Centres of the Circles and the Point of Contact will be all in the Same Right Line.

LET the two circles  $ABC$ ,  $ADE$ , touch one another externally at the point  $A$ ; then will the point of contact  $A$  and the centres of the two circles be all in the same right line.

For, let  $F$  be the centre of the circle  $ABC$ , through which draw the diameter  $AFC$ , and produce it to the other circle at  $E$ . Then, if the centre of the circle  $ADE$  can be out of the line  $FE$ , let it, if possible, be supposed in some other point  $G$ ; and draw the lines  $AG$ ,  $FBDG$ , cutting the two circles in  $B$  and  $D$ .

Then, in the triangle  $AFG$ , the sum of the two sides  $AF$ ,  $AG$ , is greater than the third side  $FG$  (th. 10). But,  $F$  and  $G$  being the centres of the two circles, the two radii  $GA$ ,  $GD$ , are equal, as are also the two radii  $AF$ ,  $FB$ . Hence the sum of  $GA$ ,  $AF$ , is equal to the sum of  $GD$ ,  $BF$ ; and therefore this latter sum also,  $GD$ ,  $BF$ , is greater than  $GF$ , which is absurd. Consequently the centre  $G$  cannot be out of the line  $FE$ . Q. E. D.



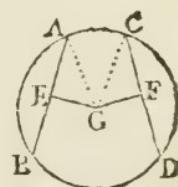
## THEOREM XLV.

Any two Chords in a Circle, which are Equally Distant from the Centre, are Equal to each other; or if they be Equal to each other, they will be Equally Distant from the Centre.

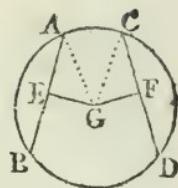
LET  $AB$ ,  $CD$ , be any two chords at equal distances from the centre  $G$ ; then will these two chords  $AB$ ,  $CD$ , be equal to each other.

For, draw the two radii  $GA$ ,  $GC$ , and the two perpendiculars  $GE$ ,  $GF$ , which are the equal distances from the centre  $G$ .

Then, the two right-angled triangles  $GAE$ ,  $GCF$ , having the side  $GA$  equal the side  $GC$ , and the side  $GE$  equal the



side  $GF$ , and the angle at  $E$  equal to the angle at  $F$ , therefore the two triangles  $GAE$ ,  $GCF$ , are identical (th. 2), and have the line  $AE$  equal the line  $CF$ . But  $AB$  is the double of  $AE$ , and  $CD$  is the double of  $CF$  (th. 41); therefore  $AB$  is equal  $CD$  (by ax. 6). Q. E. D.



Again, if the chord  $AB$  be equal to the chord  $CD$ ; then will their distances from the centre,  $GE$ ,  $GF$ , also be equal to each other.

For, since  $AB$  is equal  $CD$  by supposition, the half  $AE$  is equal the half  $CF$ . Also the radii  $GA$ ,  $GC$ , being equal, as well as the right angles  $E$  and  $F$ , therefore the third sides are equal (th. 2), or the distance  $GE$  equal the distance  $GF$ .

Q. E. D.

*Corol.* Hence, if two right-angled triangles having equal hypothenuses, have two other sides also equal; then will the third sides be equal, and the two triangles identical, or equal in all respects.

#### THEOREM XLVI.

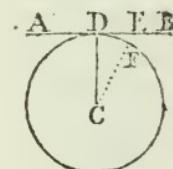
A Right Line Perpendicular to the Extremity of a Radius, is a Tangent to the Circle.

LET the line  $ADB$  be perpendicular to the radius  $CD$  of a circle; then shall  $AB$  touch the circle in the point  $D$  only.

For, from any other point  $E$  in the line  $AB$ , draw  $CDE$  to the centre, meeting the circle in  $F$ .

Then, because the angle  $D$ , of the triangle  $CDE$ , is right-angled at  $D$ , the angle at  $E$  is acute (th. 17. cor. 3), and consequently less than the angle  $D$ . But the greater side is always opposite to the greater angle (th. 9); therefore the side  $CE$  is greater than the side  $CD$ , or greater than its equal  $CF$ . Hence the point  $E$  is without the circle; and the same for every other point in the line  $AB$ . Consequently the whole line is without the circle, and meets it in the point  $D$  only.

*Corol.* Hence it follows, that a perpendicular is the shortest line which can be drawn from any point to a given line; since the perpendicular  $CD$  is shorter than any other line which can be drawn from the point  $C$  to the line  $AB$ , the same as theorem 21.



## THEOREM XLVII.

If a Right Line be a Tangent to a Circle, a Radius drawn to the Point of Contact will be Perpendicular to the Tangent.

LET the line  $AB$  touch the circumference of a circle at the point  $D$ ; then will the radius  $CD$  be perpendicular to the tangent  $AB$ . [See the last figure.]

For, the line  $AB$  being wholly without the circumference except at the point  $D$ , every other line, as  $CE$ , drawn from the centre  $C$  to the line  $AB$ , must pass out of the circle to arrive at this line. The line  $CD$  is therefore the shortest that can be drawn from the point  $C$  to the line  $AB$ , and consequently (th. 21) is perpendicular to that line.

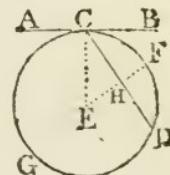
*Corol.* Hence, conversely, a line drawn perpendicular to a tangent, at the point of contact, passes through the centre of the circle.

## THEOREM XLVIII.

The Angle formed by a Tangent and Chord is Measured by Half the Arc of that Chord.

Let  $AB$  be a tangent to a circle, and  $CD$  a chord drawn from the point of contact  $C$ ; then is the angle  $BCD$  measured by half the arc  $CED$ , and the angle  $ACD$  measured by half the arc  $CGD$ .

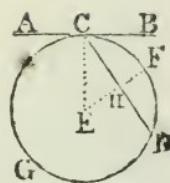
For, draw the radius  $EC$  to the point of contact, and the radius  $EF$  perpendicular to the chord at  $H$ .



Then, the radius  $EF$ , being perpendicular to the chord  $CD$ , bisects the arc  $CED$  (th. 41). Therefore  $CF$  is half the arc  $CED$ .

In the triangle  $CEH$ , the angle  $H$  being a right angle, the sum of the two remaining angles  $E$  and  $C$  is equal to a right angle (corol. 3, th. 17), which is equal to the angle  $BCE$ , because the radius  $CE$  is perpendicular to the tangent. From each of these equals take away the common part or angle  $C$ , and there remains the angle  $E$  equal to the angle  $BCE$ . But the angle  $E$  is measured by the arc  $CF$  (def. 57), which is the half of  $CED$ ; therefore the equal angle  $BCE$  must also have the same measure, namely, half the arc  $CED$  of the chord  $CD$ .

Again, the line  $GEF$ , being perpendicular to the chord  $CD$ , bisects the arc  $CGD$  (th. 41). Therefore  $CG$  is half the arc  $CGD$ . Now, since the line  $CE$ , meeting  $FG$ , makes the sum of the two angles at  $E$  equal to two right angles (th. 6), and the line  $CD$  makes with  $AB$  the sum of the two angles at  $C$  equal to two right angles; if from these two equal sums there be taken away the parts or angles  $CEH$  and  $BCH$ , which have been proved equal, there remains the angle  $CEG$  equal to the angle  $ACH$ . But the former of these,  $CEG$ , being an angle at the centre, is measured by the arc  $CG$  (def. 57); consequently the equal angle  $ACD$  must also have the same measure  $CG$ , which is half the arc  $CGD$  of the chord  $CD$ . Q. E. D.



*Corol.* 1. The sum of two right angles is measured by half the circumference. For the two angles  $BCD$ ,  $ACD$ , which make up two right angles, are measured by the arcs  $CF$ ,  $CG$ , which make up half the circumference,  $FG$  being a diameter.

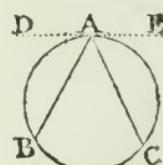
*Corol.* 2. Hence also one right angle must have for its measure a quarter of the circumference, or 90 degrees.

#### THEOREM XLIX.

An Angle at the Circumference of a Circle, is Measured by Half the Arc that subtends it.

LET  $BAC$  be an angle at the circumference; it has for its measure, half the arc  $BC$  which subtends it.

For, suppose the tangent  $DE$  passing through the point of contact  $A$ . Then, the angle  $DAC$  being measured by half the arc  $ABC$ , and the angle  $DAB$  by half the arc  $AB$  (th. 48); it follows, by equal subtraction, that the difference, or angle  $BAC$ , must be measured by half the arc  $BC$ , which it stands upon. Q. E. D.



## THEOREM L.

All Angles in the Same Segment of a Circle, or Standing on the same Arc, are Equal to each other.

LET  $ACB$ ,  $ADB$ , be two angles in the same segment  $ACDB$ , or, which is the same thing, standing on the same arc  $AEB$ ; then will the angle  $ACB$  be equal to the angle  $ADB$ .

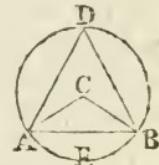
For each of these angles is measured by half the arc  $AEB$ , and thus, having equal measures, they are equal to each other (ax. 11).



## THEOREM LI.

An Angle at the Centre of a Circle is Double the Angle at the Circumference, when both of them stand on the same Arc.

LET  $ACB$  be an angle at the centre  $C$ , and  $ADB$  an angle at the circumference, both standing on the same arc or same chord  $AB$ : then will the angle  $C$  be double of the angle  $D$ , or the angle  $D$  equal to half the angle  $C$ .



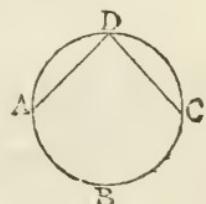
For the angle at the centre  $C$  is measured by the whole arc  $AEB$  (def. 57), and the angle at the circumference  $D$  is measured by half the same arc  $AEB$  (th. 49); therefore the angle  $D$  is only half the angle  $C$ , or the angle  $C$  double the angle  $D$ .

## THEOREM LII.

An Angle in a Semicircle, is a Right Angle.

IF  $ABC$  or  $ADC$  be a Semicircle; then any angle  $ADC$  in that semicircle, is a right angle.

For, the angle  $D$ , at the circumference, is measured by half the arc  $ABC$  (th. 49), that is, by a quadrant of the circumference. But a quadrant is the measure of a right angle (corol. 4, th. 6; or corol. 2, th. 48). Therefore the angle  $A$  is a right angle.

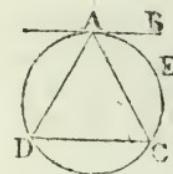


## THEOREM LIII.

The Angle formed by a Tangent to a Circle and a Chord drawn from the Point of Contact, is Equal to the Angle in the Alternate Segment.

IF  $AB$  be a tangent,  $AC$  a chord, and  $D$  any angle in the alternate segment  $ADC$ ; then will the angle  $D$  be equal to the angle  $BAC$  made by the tangent and chord of the arc  $AEC$ .

For the angle  $D$ , at the circumference, is measured by half the arc  $AEC$  (th. 49); and the angle  $BAC$ , made by the tangent and chord, is also measured by the same half arc  $AEC$  (th. 48); therefore these two angles are equal (ax. 11).

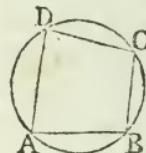


## THEOREM LIV.

The Sum of any Two Opposite Angles of a Quadrangle Inscribed in a Circle, is Equal to Two Right Angles.

LET  $ABCD$  be any quadrilateral inscribed in a circle; then shall the sum of the two opposite angles  $A$  and  $C$ , or  $B$  and  $D$ , be equal to two right angles.

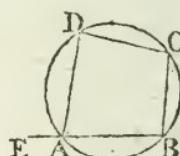
For the angle  $A$  is measured by half the arc  $DCB$ , which it stands upon, and the angle  $C$  by half the arc  $DAB$  (th. 49); therefore the sum of the two angles  $A$  and  $C$  is measured by half the sum of these two arcs, that is, by half the circumference. But half the circumference is the measure of two right angles (corol. 4, th. 6); therefore the sum of the two opposite angles  $A$  and  $C$  is equal to two right angles. In like manner, it is shewn that the sum of the other two opposite angles,  $D$  and  $B$ , is equal to two right angles. Q. E. D.



## THEOREM LV.

If any Side of a Quadrangle, Inscribed in a Circle, be Produced, the Outward Angle will be Equal to the Inward Opposite Angle.

IF the side  $AB$ , of the quadrilateral  $ABCD$ , inscribed in a circle, be produced to  $E$ ; the outward angle  $DAE$  will be equal to the inward opposite angle  $C$ .



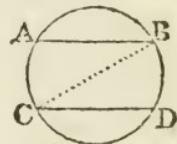
For,

For, the sum of the two adjacent angles  $\angle DAE$  and  $\angle DAB$  is equal to two right angles (th. 6); and the sum of the two opposite angles  $c$  and  $\angle DAB$  is also equal to two right angles (th. 54); therefore the sum of the two angles  $\angle DAE$  and  $\angle DAB$  is equal to the sum of the two  $c$  and  $\angle DAB$  (ax. 1). From each of these equals taking away the common angle  $\angle DAB$ , there remains the angle  $\angle DAE$  equal the angle  $c$ . Q. E. D.

## THEOREM, LVI.

Two Parallel Chords Intercept Equal Arcs.

LET the two chords  $AB$ ,  $CD$ , be parallel; then will the arcs  $AC$ ,  $BD$ , be equal; or  $AC = BD$ .

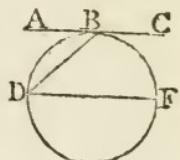


For, draw the line  $BC$ . Then, because the lines  $AB$ ,  $CD$ , are parallel, the alternate angles  $B$  and  $C$  are equal (th. 12). But the angle at the circumference  $B$ , is measured by half the arc  $AC$  (th. 49); and the other angle at the circumference  $C$  is measured by half the arc  $BD$ : the halves of the arcs  $AC$ ,  $BD$ , and consequently the arcs themselves, are therefore equal. Q. E. D.

## THEOREM LVII.

If a Tangent and Chord be Parallel to each other, they Intercept Equal Arcs.

LET the tangent  $ABC$  be parallel to the chord  $DF$ ; then are the arcs  $BD$ ,  $BF$ , equal; that is,  $BD = BF$ .



For, draw the chord  $BD$ . Then, because the lines  $AB$ ,  $DF$ , are parallel, the alternate angles  $D$  and  $B$  are equal (th. 12). But the angle  $B$ , formed by a tangent and a chord, is measured by half the arc  $BD$  (th. 48); and the angle at the circumference  $D$  is measured by half the arc  $BF$  (th. 49); the arcs  $BD$ ,  $BF$ , are therefore equal. Q. E. D.

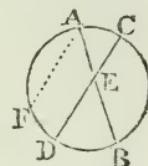
## THEOREM LVIII.

The Angle formed, Within a Circle, by the Intersection of two Chords; is Measured by Half the Sum of the Two Arcs Intercepted by those Chords.

LET the two chords  $AB$ ,  $CD$ , intersect at the point  $E$ : the angle  $AEC$ , or  $DEB$ , is measured by half the sum of two arcs  $AC$ ,  $DB$ .

For, draw the chord  $AF$  parallel to  $CD$ . Then, because the lines  $AF$ ,  $CD$ , are parallel, and  $AB$  cuts them. the angles on the same side  $A$  and  $DEB$  are equal (th. 14). But the angle at the circumference  $A$  is measured by half the arc  $BF$ , or of the sum of  $FD$  and  $DB$  (th. 49); therefore the angle  $E$  is also measured by half the sum of  $FD$  and  $DB$ .

Again, because the chords  $AF$ ,  $CD$ , are parallel, the arcs  $AC$ ,  $FD$ , are equal (th. 56); therefore the sum of the two arcs  $AC$ ,  $DB$ , is equal to the sum of the two  $FD$ ,  $DE$ ; and consequently the angle  $E$ , which is measured by half the latter sum, is also measured by half the former. Q. E. D.

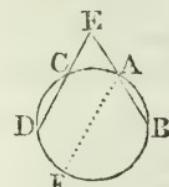


## THEOREM LIX.

The Angle formed, Without a Circle, by two Secants, is Measured by Half the Difference of the Intercepted Arcs.

LET the angle  $E$  be formed by two secants  $AB$  and  $CD$ , this angle is measured by half the difference of the two arcs  $AC$ ,  $DB$ , intercepted by the two secants.

Draw the chord  $AF$  parallel to  $CD$ . Then, because the lines  $AF$ ,  $CD$ , are parallel, and  $AB$  cuts them, the angles on the same side  $A$  and  $BED$  are equal (th. 14). But the angle  $A$ , at the circumference, is measured by half the arc  $BF$  (th. 49), or of the difference of  $DF$  and  $DB$ : therefore the equal angle  $E$  is also measured by half the difference of  $DF$ ,  $DB$ .



Again, because the chords  $AF$ ,  $CD$ , are parallel, the arcs  $AC$ ,  $FD$ , are equal (th. 56); therefore the difference of the two

two arcs  $AC$ ,  $DB$ , is equal to the difference of the two  $DF$ ,  $DB$ . Consequently the angle  $E$ , which is measured by half the latter difference, is also measured by half the former.

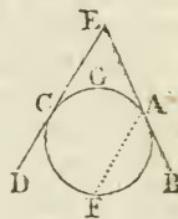
Q. E. D.

### THEOREM LX.

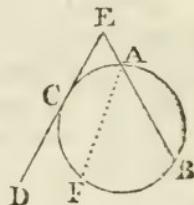
The Angle formed by two Tangents, is Measured by Half the Difference of the two Intercepted Arcs.

LET  $EB$ ,  $ED$ , be two tangents to a circle at the points  $A$ ,  $C$ ; then the angle  $E$  is measured by half the difference of the two arcs  $CFA$ ,  $CGA$ .

For, draw the chord  $AF$  parallel to  $ED$ . Then, because the lines  $AF$ ,  $ED$ , are parallel, and  $EB$  meets them, the angles on the same side  $A$  and  $E$  are equal (th. 14). But the angle  $A$ , formed by the chord  $AF$  and tangent  $AB$ , is measured by half the arc  $AF$  (th. 48); therefore the equal angle  $E$  is also measured by half the same arc  $AF$ , or half the difference of the arcs  $CFA$  and  $CGA$  (th. 57).



*Corol.* In like manner it is proved, that the angle  $E$ , formed by a tangent  $ECD$  and a secant  $EAB$ , is measured by half the difference of the two intercepted arcs  $CA$  and  $CFB$ .



### THEOREM LXI.

If two Lines, meeting a Circle each in two Points, Cut one another, either Within it or Without it; the Rectangle of the Parts of the one, will be Equal to the Rectangle of the Parts of the other; the Parts of each being measured from the point of meeting to the two intersections with the circumference.

LET

LET the two chords  $AB$ ,  $CD$ , meet each other in  $E$ ; the rectangle of  $AE$ ,  $EB$ , will be equal to the rectangle of  $CE$ ,  $ED$ . Or,  $AE \cdot EB = CE \cdot ED$ .

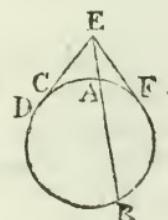
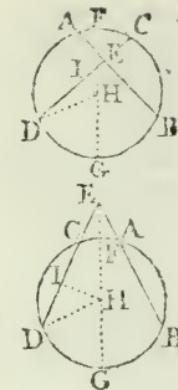
For, through the point  $E$  draw the diameter  $FG$ ; also, from the centre  $H$  draw the radius  $DH$ , and  $HI$  perpendicular to  $CD$ .

Then, since  $DEH$  is a triangle, and the perp.  $HI$  bisects the chord  $CD$  (th. 41), the line  $CE$  is equal to the difference of the segments  $DI$ ,  $EI$ , the sum of them being  $DE$ . Also, because  $H$  is the centre of the circle, and the radii  $DH$ ,  $FH$ ,  $GH$ , are all equal, the line  $EG$  is equal to the sum of the sides  $DH$ ,  $HE$ ; and  $EF$  is equal to their difference.

But the rectangle of the sum and difference of the two sides of a triangle, is equal to the rectangle of the sum and difference of the segments of the base (corol. th. 25); therefore the rectangle of  $FE$ ,  $EG$ , is equal to the rectangle of  $CE$ ,  $ED$ . In the same manner it is proved that the rectangle of  $FE$ ,  $EG$ , is equal to the rectangle of  $AE$ ,  $EB$ . Consequently the rectangle of  $AE$ ,  $EB$ , is also equal to the rectangle of  $CE$ ,  $ED$  (ax. 1). Q. E. D.

*Corol. 1.* When one of the lines in the second case, as  $DE$ , by revolving about the point  $E$ , comes into the position of the tangent  $EC$  or  $ED$ , the two points  $C$  and  $D$  running into one; then the rectangle  $CE$ ,  $ED$ , becomes the square of  $CE$ , because  $CE$  and  $DE$  are then equal. Consequently the rectangle of the parts of the secant,  $AE \cdot EB$  is equal to the square of the tangent  $CE^2$ .

*Corol. 2.* Hence both the tangents  $EC$ ,  $EF$ , drawn from the same point  $E$ , are equal; since the square of each is equal to the same rectangle or quantity,  $AE \cdot EB$ .



#### THEOREM LXII.

In Equiangular Triangles, the Rectangles of the Corresponding or Like Sides, taken alternately, are Equal.

LET

LET  $ABC$ ,  $DEF$ , be two equiangular triangles, having the angle  $A$  = the angle  $D$ , the angle  $B$  = the angle  $E$ , and the angle  $C$  = the angle  $F$ ; also the like sides  $AB$ ,  $DE$ , and  $AC$ ,  $DF$ , being those opposite the equal angles: then will the rectangle of  $AB$ ,  $DF$ , be equal to the rectangle of  $AC$ ,  $DE$ .

In  $BA$  produced take  $AG$  equal to  $DF$ ; then through the three points  $B$ ,  $C$ ,  $G$ , conceive a circle  $BCGH$  to be described, meeting  $CA$  produced at  $H$ , and join  $GH$ .

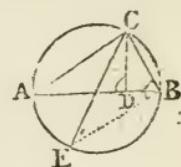
Then the angle  $G$  is equal to the angle  $C$  on the same arc  $BH$ , and the angle  $H$  equal to the angle  $B$  on the same arc  $CG$  (th. 50); also the opposite angles at  $A$  are equal (th. 7): therefore the triangle  $AGH$  is equiangular to the triangle  $ACB$ , and consequently to the triangle  $DFE$  also. But the two like sides  $AC$ ,  $DF$ , are also equal by superposition; consequently the two triangles  $AGH$ ,  $DFE$ , are identical (th. 2), having the two sides  $AG$ ,  $AH$ , equal to the two  $DF$ ,  $DE$ , each to each.

But the rectangle  $GA \cdot AB$  is equal to the rectangle  $HA \cdot AC$  (th. 61): consequently the rectangle  $DF \cdot AB$  is equal the rectangle  $DE \cdot AC$ . Q. E. D.

## THEOREM LXIII.

The Rectangle of the two Sides of any Triangle, is Equal to the Rectangle of the Perpendicular on the third Side and the Diameter of the Circumscribing Circle.

LET  $CD$  be the perpendicular, and  $CE$  the diameter of the circle about the triangle  $ABC$ ; then the rectangle  $AC \cdot CB$  is = the rectangle  $CD \cdot CE$ .



For, join  $BE$ : then in the two triangles  $ACD$ ,  $ECB$ , the angles  $A$  and  $E$  are equal, standing on the same arc  $BC$  (th. 50); also the right angle  $D$  is equal the angle  $B$ , which is also a right angle, being in a semicircle (th. 52): therefore these two triangles have also their third angles equal, and are equiangular. Hence,  $AC$ ,  $CE$ , and  $CD$ ,  $CB$ , being like sides, subtending the equal angles, the rectangle  $AC \cdot CB$  of the first and last of them, is equal to the rectangle  $CE \cdot CD$  of the other two (th. 62).

## THEOREM LXIV.

The Square of a Line Bisecting any Angle of a Triang'e, and terminating in the Opposite Side, together with the Rectangle of the two Segments of that Side, is Equal to the Rectangle of the two Sides including the Bisected Angle.

LET  $CD$  bisect the angle  $C$  of the triangle  $ABC$ : then the square of  $CD$  + the rectangle  $AD \cdot DB$  is = the rectangle  $AC \cdot CB$ .

For, let  $CD$  be produced to meet the circumfering circle at  $E$ , and join  $AE$ .

Then the two triangles  $ACE$ ,  $BCD$ , are equiangular: for the angles at  $C$  are equal by supposition, and the angles  $B$  and  $E$  are equal, standing on the same arc  $AC$  (th. 50); consequently the third angles at  $A$  and  $D$  are equal (corol. 1, th. 17): also  $AC$ ,  $CD$ , and  $CE$ ,  $CB$ , are like or corresponding sides, being opposite to equal angles: therefore the rectangle  $AC \cdot CB$  is = the rectangle  $CD \cdot CE$  (th. 62). But the rectangle  $CD \cdot CE$  is =  $CD$  + the rectangle  $CD \cdot DE$  (th. 30); therefore also the rectangle  $AC \cdot CB$  is =  $CD$  +  $CD \cdot DE$ , or equal  $CD^2$  +  $AD \cdot DB$ , since  $CD \cdot DE$  is =  $AD \cdot DB$  (th. 61).

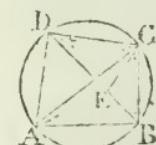


Q. E. D.

## THEOREM LXV.

The Rectangle of the two Diagonals of any Quadrangle Inscribed in a Circle, is equal to the Sum of the two Rectangles of the Opposite Sides.

LET  $ABCD$  be any quadrilateral inscribed in a circle, and  $AC$ ,  $BD$ , its two diagonals: then the rectangle  $AC \cdot BD$  is = the rectangle  $AB \cdot DC$  + the rectangle  $AD \cdot BC$ .



For, let  $CE$  be drawn, making the angle  $BCE$  equal to the angle  $DCA$ . Then the two triangles  $ACB$ ,  $BCE$ , are equiangular; for the angles  $A$  and  $B$  are equal, standing on the same arc  $DC$ ; and the angles  $DCA$ ,  $BCE$ , are equal by supposition; consequently the third angles  $ADC$ ,  $BEC$ , are also equal: also,  $AC$ ,  $BC$ , and  $AD$ ,  $BE$ , are like or corresponding sides, being opposite to the equal angles: therefore the rect.  $AC \cdot BE$  is = the rectangle  $AD \cdot BC$  (th. 62).

Again,

Again, the two triangles ABC, DEC, are equiangular: for the angles BAC, BDC, are equal, standing on the same arc BC; and the angle DCE is equal the angle BCA, by adding the common angle ACE to the two equal angles BCA, BCE; therefore the third angles E and ABC are also equal: but AC, DC, and AB, DE, are the like sides: therefore the rectangle AC . DE is = the rectangle AB . DC (th. 62).

Hence, by equal additions, the sum of the rectangles AC . BE + AC . DE is = AD . BC + AB . DC. But the sum of the rectangles AC . BE + AC . DE is = the rectangle AC . BD (th. 30): therefore the rectangle AC . ED is equal the rect. AD . BC + the rect. AB . DC (ax. 1). Q. E. D.

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## OF RATIOS AND PROPORTIONS.

### DEFINITIONS.

DEF. 76. RATIO is the proportion or relation which one magnitude bears to another magnitude of the same kind, with respect to quantity.

*Note.* The measure, or quantity, of a ratio, is conceived, by considering what part or parts the leading quantity, called the Antecedent, is of the other, called the Consequent; or what part or parts the number expressing the quantity of the former, is of the number denoting in like manner the latter. So, the ratio of a quantity expressed by the number 2, to a like quantity expressed by the number 6, is denoted by 6 divided by 2, or  $\frac{6}{2}$  or 3: the number 2 being 3 times contained in 6, or the third part of it. In like manner, the ratio of the quantity 3 to 6, is measured by  $\frac{6}{3}$  or 2; the ratio of 4 to 6 is  $\frac{6}{4}$  or  $1\frac{1}{2}$ ; that of 6 to 4 is  $\frac{4}{6}$  or  $\frac{2}{3}$ ; &c.

77. Proportion is an equality of ratios. Thus,

78. Three quantities are said to be Proportional, when the ratio of the first to the second is equal to the ratio of the second to the third. As of the three quantities A (2), B (4), C (8), where  $\frac{A}{B} = \frac{B}{C} = 2$ , both the same ratio.

79. Four quantities are said to be Proportional, when the ratio of the first to the second, is the same as the ratio of the third to the fourth. As of the four, A (2), B (4), C (5), D (10), where  $\frac{A}{B} = \frac{C}{D} = 2$ , both the same ratio.

*Note.* To denote that four quantities, A, B, C, D, are proportional, they are usually stated or placed thus,  $A : B :: C : D$ ; and read thus, as A is to B so is C to D. But when three quantities are proportional, the middle one is repeated, and they are written thus,  $A : B :: B : C$ .

80. Of three proportional quantities, the middle one is said to be a Mean Proportional between the other two; and the last, a Third Proportional to the first and second.

81. Of four proportional quantities, the last is said to be a Fourth Proportional to the other three, taken in order.

82. Quantities are said to be Continually Proportional, or in Continued Proportion, when the ratio is the same between every two adjacent terms, viz. when the first is to the second, as the second to the third, as the third to the fourth, as the fourth to the fifth, and so on, all in the same common ratio.

As in the quantities 1, 2, 4, 8, 16, &c; where the common ratio is equal to 2.

83. Of any number of quantities, A, B, C, D, the ratio of the first A, to the last D, is said to be Compounded of the ratios of the first to the second, of the second to the third, and so on the last.

84. Inverse ratio is, when the antecedent is made the consequent, and the consequent the antecedent.—Thus, if  $1 : 2 :: 3 : 6$ ; then inversely,  $2 : 1 :: 6 : 3$ .

85. Alternate proportion is, when antecedent is compared with antecedent, and consequent with consequent.—As, if  $1 : 2 :: 3 : 6$ ; then, by alternation, or permutation, it will be  $1 : 3 :: 2 : 6$ .

86. Compounded ratio is, when the sum of the antecedent and consequent is compared, either with the consequent, or with the antecedent.—Thus, if  $1 : 2 :: 3 : 6$ , then by composition,  $1 + 2 : 1 :: 3 + 6 : 3$ , and  $1 + 2 : 2 :: 3 + 6 : 6$ .

87. Divided ratio, is when the difference of the antecedent and consequent is compared, either with the antecedent or with the consequent.—Thus, if  $1 : 2 :: 3 : 6$ , then, by division,  $2 - 1 : 1 :: 6 - 3 : 3$ , and  $2 - 1 : 2 :: 6 - 3 : 6$ .

*Note.* The term Divided, or Division, here means subtracting, or parting; being used in the sense opposed to compounding, or adding, in def. 86.

## THEOREM LXVI.

Equimultiples of any two Quantities are in the Same Ratio as the Quantities themselves.

LET A and B be any two quantities, and  $m_A$ ,  $m_B$ , any equimultiples of them,  $m$  being any number whatever: then will  $m_A$  and  $m_B$  have the same ratio as A and B, or  $A : B :: m_A : m_B$ .

For  $\frac{m_B}{m_A} = \frac{B}{A}$ , the same ratio.

*Corol.* Hence, like parts of quantities have the same ratio as the wholes; because the wholes are equimultiples of the like parts, or A and B are like parts of  $m_A$  and  $m_B$ .

## THEOREM LXVII.

If Four Quantities, of the Same Kind, be Proportionals; they will be in Proportion by Alternation or Permutation, or the Antecedents will have the Same Ratio as the Consequents.

LET  $A : B :: m_A : m_B$ ; then will  $A : m_A :: B : m_B$ .

For  $\frac{m_A}{A} = m$ , and  $\frac{m_B}{B} = m$ , both the same ratio.

## THEOREM LXVIII.

If Four Quantities be Proportional; they will be in Proportion by Inversion, or Inversely.

LET  $A : B :: m_A : m_B$ ; then will  $B : A :: m_B : m_A$ .

For  $\frac{m_A}{m_B} = \frac{A}{B}$ , both the same ratio.

## THEOREM LXIX.

If Four Quantities be Proportional; they will be in Proportion by Composition and Division.

LET  $A : B :: m_A : m_B$ ;

Then will  $B \pm A : A :: m_B \pm m_A : m_A$ ,  
and  $B \pm A : B :: m_B \pm m_A : m_B$ .

For,  $\frac{m_A}{m_B \pm m_A} = \frac{A}{B \pm A}$ ; and  $\frac{m_B}{m_B \pm m_A} = \frac{B}{B \pm A}$ .

*Corol.*

*Corol.* It appears from hence, that the Sum of the Greatest and Least of four proportional quantities, of the same kind, exceeds the Sum of the Two Means. For, since - - - -  $A : A + B :: m_A : m_A + m_B$ , where  $A$  is the least, and  $m_A + m_B$  the greatest; then  $\overline{m + 1} \cdot A + m_B$ , the sum of the greatest and least, exceeds  $\overline{m + 1} \cdot A + B$  the sum of the two means.

## THEOREM LXX.

If, of Four Proportional Quantities, there be taken any Equimultiples whatever of the two Antecedents, and any Equimultiples whatever of the two Consequents; the quantities resulting will still be proportional.

LET  $A : B :: m_A : m_B$ ; also, let  $p_A$  and  $p_{mA}$  be any equimultiples of the two antecedents, and  $q_B$  and  $q_{mB}$  any equimultiples of the two consequents; then will - - - -  $p_A : q_B :: p_{mA} : q_{mB}$ .

For  $\frac{q_{mB}}{p_{mA}} = \frac{q_B}{p_A}$ , both the same ratio.

## THEOREM LXXI.

If there be Four Proportional Quantities, and the two Consequents be either Augmented or Diminished by Quantities that have the Same Ratio as the respective Antecedents; the Results and the Antecedents will still be Proportionals.

LET  $A : B :: m_A : m_B$ , and  $n_A$  and  $n_{mA}$  any two quantities having the same ratio as the two antecedents; then will  $A : B \pm n_A :: m_A : m_B \pm n_{mA}$ .

For  $\frac{m_B \pm n_{mA}}{m_A} = \frac{B \pm n_A}{A}$ , both the same ratio.

## THEOREM LXXII.

If any Number of Quantities be Proportional; either of the Antecedents will be to its Consequent, as the Sum of all the Antecedents is to the Sum of all the Consequents.

LET  $A : B :: m_A : m_B :: n_A : n_B, \&c$ ; then will - - - -  $A : B :: A + m_A + n_A : B + m_B + n_B, \&c$ .

For  $\frac{B + m_B + n_B}{A + m_A + n_A} = \frac{B}{A}$ , the same ratio.

## THEOREM

## THEOREM LXXIII.

If a Whole Magnitude be to a Whole, as a Quantity taken from the first, is to a Quantity taken from the other ; the Remainder will be to the Remainder, as the whole to the whole.

LET  $A : B :: \frac{m}{n} A : \frac{m}{n} B$ ;

then will  $A : B :: A - \frac{m}{n} A : B - \frac{m}{n} B$ .

For  $\frac{B - \frac{m}{n} B}{A - \frac{m}{n} A} = \frac{B}{A}$ , both the same ratio.

## THEOREM LXXIV.

If Quantities be Proportional ; their Squares, or Cubes, or any Like Powers, or Roots, of them, will also be Proportional.

LET  $A : B :: m_A : m_B$ ; then will  $A^n : B^n :: m^n A^n : m^n B^n$ .

For  $\frac{m^n B^n}{m^n A^n} = \frac{B^n}{A^n}$ , both the same ratio.

## THEOREM LXXV.

If there be two Sets of Proportionals : then the Products of Rectangles of the Corresponding Terms will also be Proportional.

LET  $A : B :: m_A : m_B$ ,

and  $C : D :: n_C : n_D$ ;

then will  $AC : BD :: m_A n_C : m_B n_D$ .

For  $\frac{m_A n_D}{m_A n_C} = \frac{BD}{AC}$ , both the same ratio.

## THEOREM LXXVI.

If Four Quantities be Proportional ; the Rectangle or Product of the two Extremes, will be Equal to the Rectangle or Product of the two Means. And the converse.

LET  $A : B :: m_A : m_B$ ;

then is  $A \times m_B = B \times m_A = m_A m_B$ , as is evident.

## THEOREM LXXVII.

If Three Quantities be Continual Proportionals ; the Rectangle or Product of the two Extremes, will be equal to the Square of the Mean. And the converse.

LET  $A, mA, m^2A$  be three proportionals,  
or  $A : mA :: mA : m^2A$ ;  
then is  $A \times mA = m^2A^2$ , as is evident.

## THEOREM LXXVIII.

If any Number of Quantities be Continual Proportionals ; the Ratio of the First to the Third, will be duplicate or the Square of the Ratio of the First and Second ; and the Ratio of the First and Fourth will be triplicate or the cube of that of the First and Second ; and so on.

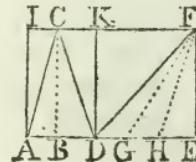
LET  $A, mA, m^2A, m^3A, \&c$ , be proportionals ;  
then is  $\frac{mA}{A} = m$ ; but  $\frac{m^2A}{A} = m^2$ ; and  $\frac{m^3A}{A} = m^3$ ; &c,

## THEOREM LXXIX.

Triangles, and also Parallelograms, having the Same Altitude, or that are between the Same Parallels, are to one another in the same Ratio as their Bases.

LET the two triangles  $ADC, DEF$ , have the same altitude, or be between the same parallels  $AE, CF$ ; then is the surface of the triangle  $ADC$  to the surface of the triangle  $DEF$ , as the base  $AD$  is to the base  $DE$ . Or,  $AD : DE ::$  the triangle  $ADC$  : the triangle  $DEF$ .

For, let the base  $AD$  be to the base  $DE$ , as any one number  $m$  (2), to any other number  $n$  (3); and divide the respective bases into those parts,  $AB, BD, DG, GH, HE$ , all equal to one another; and from the points of division draw the lines  $EC, FG, FH$ , to the vertices  $C$  and  $F$ . Then will these lines divide the triangles  $ADC, DEF$ , into the same number of parts as their bases, each equal to the triangle  $ABC$ , because those triangular parts have equal bases and altitude (corol. 2, th. 25); namely, the triangle  $ABC$ , equal to each of the triangles  $BDC, DFG, CFH, HFE$ . So that the triangle  $ADC$  is to the triangle  $DEF$ , as the number of parts



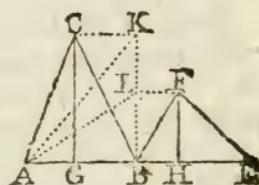
parts  $m$  (2) of the former, to the number  $n$  (3) of the latter, that is, as the base  $AD$  to the base  $DE$  (def. 79).

In like manner, the parallelogram  $ADKI$  is to the parallelogram  $DEFK$ , as the base  $AD$  is to the base  $DE$ ; each of these having the same ratio as the number of their parts,  $m$  to  $n$ . Q. E. D.

## THEOREM LXXX.

Triangles and Parallelograms, having Equal Bases, are to each other as their Altitudes.

LET  $ABC$ ,  $BEF$ , be two triangles having the equal bases  $AB$ ,  $BE$ , and whose altitudes are the perpendiculars  $CG$ ,  $FH$ ; then will the triangle  $ABC$  : the triangle  $BEF$  ::  $CG$  :  $FH$ .



For, let  $BK$  be perpendicular to  $AB$  and equal to  $CG$ ; in which let there be taken  $BL = FH$ ; drawing  $AK$  and  $AL$ .

Then, triangles of equal bases and heights being equal (corol. 2. th. 25), the triangle  $ABK$  is =  $ABC$ , and the triangle  $ABL$  =  $BEF$ . But, considering now  $ABK$ ,  $ABL$ , as two triangles on the bases  $BK$ ,  $BL$ , and having the same altitude  $AB$ , these will be as their bases (th. 79), namely, the triangle  $ABK$  : the triangle  $ABL$  ::  $BK$  :  $BL$ .

But the triangle  $ABK$  =  $ABC$ , and the triangle  $ABL$  =  $BEF$ , also  $BK$  =  $CG$ , and  $BL$  =  $FH$ .

Theref. the triangle  $ABC$  : triangle  $BEF$  ::  $CG$  :  $FH$ .

And since parallelograms are the doubles of these triangles, having the same bases and altitudes, they will likewise have to each other the same ratio as their altitudes. Q. E. D.

*Corol.* Since, by this theorem, triangles and parallelograms, when their bases are equal, are to each other as their altitudes; and by the foregoing one, when their altitudes are equal, they are to each other as their bases; therefore universally, when neither are equal, they are to each other in the compound ratio, or as the rectangle or product of their bases and altitudes.

## THEOREM LXXXI.

If Four Lines be Proportional; the Rectangle of the Extremes will be Equal to the Rectangle of the Means. And, conversely, if the Rectangle of the Extremes, of four Lines, be equal to the Rectangle of the Means, the Four Lines, taken alternately, will be Proportional.

LET the four lines A, B, C, D, be proportionals, or  $A : B :: C : D$ ; then will the rectangle of A and D be equal to the rectangle of B and C; or the rectangle  $A \cdot D = B \cdot C$ .

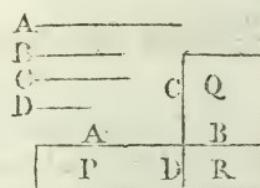
For, let the four lines be placed, with their four extremities meeting in a common point, forming at the point four right angles; and draw lines parallel to them to complete the rectangles P, Q, R, where P is the rectangle of A and D, Q the rectangle of B and C, and R the rectangle of B and D.

Then the rectangles P and R, being between the same parallels, are to each other as their bases A and B (th. 79); and the rectangles Q and R, being between the same parallels, are to each other as their bases C and D. But the ratio of A to B is the same as the ratio of C to D by hypothesis; therefore the ratio of P to R, is the same as the ratio of Q to R; and consequently the rectangles P and Q are equal. Q. E. D.

Again, if the rectangle of A and D, be equal to the rectangle of B and C; these lines will be proportional, or  $A : B :: C : D$ .

For, the rectangles being placed the same as before: then, because parallelograms between the same parallels, are to one another as their bases, the rectangle  $P : R :: A : B$ , and  $Q : R :: C : D$ . But as P and Q are equal, by supposition, they have the same ratio to R, that is, the ratio of A to B is equal to the ratio of C to D, or  $A : B :: C : D$ . Q. E. D.

*Corol. 1.* When the two means, namely, the second and third terms, are equal, their rectangle becomes a square of the second term, which supplies the place of both the second and third. And hence it follows, that when three lines are proportionals, the rectangle of the two extremes is equal to the



the square of the mean ; and, conversely, if the rectangle of the extremes be equal to the square of the mean, the three lines are proportionals.

*Corol. 2.* Since it appears, by the rules of proportion in Arithmetic and Algebra, that when four quantities are proportional, the product of the extremes is equal to the product of the two means ; and, by this theorem, the rectangle of the extremes is equal to the rectangle of the two means ; it follows, that the area or space of a rectangle is represented or expressed by the product of its length and breadth multiplied together. And, in general, a rectangle in geometry is similar to the product of the measures of its two dimensions of length and breadth, or base and height. Also, a square is similar to, or represented by, the measure of its side multiplied by itself. So that, what is shewn of such products, is to be understood of the squares and rectangles.

*Corol. 3.* Since the same reasoning, as in this theorem, holds for any parallelograms whatever, as well as for the rectangles, the same property belongs to all kinds of parallelograms, having equal angles, and also to triangles, which are the halves of parallelograms ; namely, that if the sides about the equal angles of parallelograms, or triangles, be reciprocally proportional, the parallelograms or triangles will be equal ; and, conversely, if the parallelograms or triangles be equal, their sides about the equal angles will be reciprocally proportional.

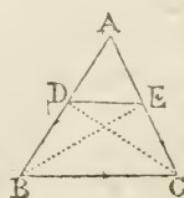
*Corol. 4.* Parallelograms, or triangles, having an angle in each equal, are in proportion to each other as the rectangles of the sides which are about these equal angles.

### THEOREM LXXXII.

If a Line be drawn in a Triangle Parallel to one of its sides, it will cut the two other sides Proportionally.

LET DE be parallel to the side BC of the triangle ABC ; then will  $AD : DB :: AE : EC$ .

For, draw BE and CD. Then the triangles DBE, DCE, are equal to each other, because they have the same base DE, and are between the same parallels DE, BC (th. 25). But the two triangles ADE, BDE, on the bases AD, DB, have the same altitude;



tude;

tude; and the two triangles  $ADE$ ,  $CDE$ , on the bases  $AE$ ,  $EC$ , have also the same altitude; and because triangles of the same altitude are to each other as their bases, therefore

the triangle  $ADE$  :  $BDE$  ::  $AD$  :  $DB$ ,  
and triangle  $ADE$  :  $CDE$  ::  $AE$  :  $EC$ .

But  $BDE$  is =  $CDE$ ; and equals must have to equals the same ratio; therefore  $AD$  :  $DB$  ::  $AE$  :  $EC$ . Q. E. D.

*Corol.* Hence, also, the whole lines  $AB$ ,  $AC$ , are proportional to their corresponding proportional segments (corol. th. 66),

viz.  $AB$  :  $AC$  ::  $AD$  :  $AE$ ,  
and  $AB$  :  $AC$  ::  $BD$  :  $CE$ .

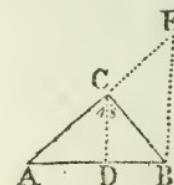
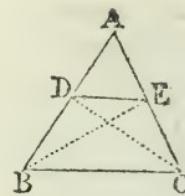
#### THEOREM LXXXIII.

**A** Right Line which Bisects any Angle of a Triangle, divides the Side opposite to the Bisected Angle into Two Segments, which are Proportional to the two other Adjacent Sides.

LET the angle  $ACB$ , of the triangle  $ABC$ , be bisected by the line  $CD$ , making the angle  $r$  equal to the angle  $s$ : then will the segment  $AD$  be to the segment  $DB$ , as the side  $AC$  is to the side  $CB$ . Or, - - -  
 $AD$  :  $DB$  ::  $AC$  :  $CB$ .

For, let  $BE$  be parallel to  $CD$ , meeting  $AC$  produced at  $E$ . Then, because the line  $BC$  cuts the two parallels  $CD$ ,  $BE$ , it makes the angle  $CBE$  equal to the alternate angle  $s$  (th. 12), and therefore also equal to the angle  $r$ , which is equal to  $s$  by the supposition. Again, because the line  $AE$  cuts the two parallels  $DC$ ,  $BE$ , it makes the angle  $E$  equal to the angle  $r$  on the same side of it (th. 14). Hence, in the triangle  $BCE$ , the angles  $s$  and  $E$ , being each equal to the angle  $r$ , are equal to each other, and consequently their opposite sides  $CB$ ,  $CE$ , are also equal (th. 3).

But now, in the triangle  $ABE$ , the line  $CD$ , being drawn parallel to the side  $BE$ , cuts the two other sides  $AB$ ,  $AE$ , proportionally (th. 82), making  $AD$  to  $DB$ , as is  $AC$  to  $CE$  or to its equal  $CB$ . Q. E. D.



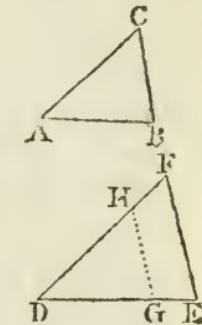
## THEOREM LXXXIV.

Equiangular Triangles are Similar, or have their Like Sides Proportional.

LET  $ABC$ ,  $DEF$ , be two equiangular triangles, having the angle  $A$  equal to the angle  $D$ , the angle  $B$  to the angle  $E$ , and consequently the angle  $C$  to the angle  $F$ ; then will  $AB : AC :: DE : DF$ .

For, make  $DG = AB$ , and  $DH = AC$ , and join  $GH$ . Then the two triangles  $ABC$ ,  $DGH$ , having the two sides  $AB$ ,  $AC$ , equal to the two  $DG$ ,  $DH$ , and the contained angles  $A$  and  $D$  also equal, are identical, or equal in all respects (th. 1), namely, the angles  $B$  and  $C$  are equal to the angles  $G$  and  $H$ . But the angles  $B$  and  $C$  are equal to the angles  $E$  and  $F$  by the hypothesis; therefore also the angles  $G$  and  $H$  are equal to the angles  $E$  and  $F$  (ax. 1), and consequently the line  $GH$  is parallel to the side  $EF$  (cor. 1, th. 14).

Hence then, in the triangle  $DEF$ , the line  $GH$ , being parallel to the side  $EF$ , divides the two other sides proportionally, making  $DG : DH :: DE : DF$  (cor. th. 82). But  $DG$  and  $DH$  are equal to  $AB$  and  $AC$ ; therefore also  $AB : AC :: DE : DF$ . Q. E. D.

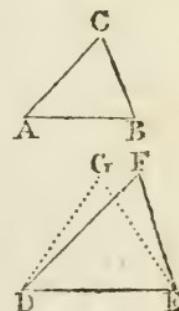


## THEOREM LXXXV.

Triangles which have their Sides Proportional, are Equiangular.

IN the two triangles  $ABC$ ,  $DEF$ , if  $AB : DE :: AC : DF :: BC : EF$ ; the two triangles will have their corresponding angles equal.

For, if the triangle  $ABC$  be not equiangular with the triangle  $DEF$ , suppose some other triangle, as  $DEG$ , to be equiangular with  $ABC$ . But this is impossible. for if the two triangles  $ABC$ ,  $DEG$ , were equiangular, their sides would be proportional (th. 84). So that,  $AB$  being to  $DE$  as  $AC$  to  $DG$ , and  $AB$  to  $DE$  as  $BC$  to  $EG$ , it follows that  $DG$  and  $EG$ , being fourth proportionals to the same three quantities,



as well as the two  $DF$ ,  $EF$ , the former  $DC$ ,  $EC$ , would be equal to the latter,  $DE$ ,  $EF$ . Thus then, the two triangles  $DEF$ ,  $DCE$ , having their three sides equal, would be identical (th. 5); which is absurd, since their angles are unequal.

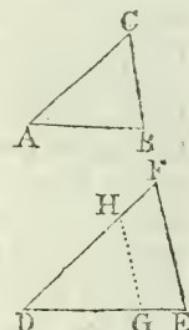
## THEOREM LXXXVI.

Triangles, which have an Angle in the one Equal to an Angle in the other, and the Sides about these angles Proportional, are Equiangular.

LET  $ABC$ ,  $DEF$ , be two triangles, having the angle  $A$  = the angle  $D$ , and the sides  $AB$ ,  $AC$ , proportional to the sides  $DE$ ,  $DF$ : then will the triangle  $ABC$  be equiangular with the triangle  $DEF$ .

For, make  $DG = AB$ , and  $DH = AC$ , and join  $GH$ .

Then, the two triangles  $ABC$ ,  $DGH$ , having two sides equal, and the contained angles  $A$  and  $D$  equal, are identical and equiangular (th. 1), having the angles  $G$  and  $H$  equal to the angles  $B$  and  $C$ . But, since the sides  $DG$ ,  $DH$ , are proportional to the sides  $DE$ ,  $DF$ , the line  $GH$  is parallel to  $EF$  (th. 82); hence the angles  $E$  and  $F$  are equal to the angles  $G$  and  $H$  (th. 14), and consequently to their equals  $B$  and  $C$ . Q. E. D.



## THEOREM LXXXVII.

In a Right-Angled Triangle, a Perpendicular from the Right Angle, is a Mean Proportional between the Segments of the Hypotenuse; and each of the Sides, about the Right Angle, is a Mean Proportional between the Adjacent Segment and the Hypotenuse.

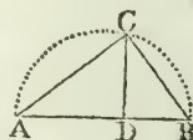
LET  $ABC$  be a right-angled triangle, and  $CD$  a perpendicular from the right angle  $B$  to the hypotenuse  $AB$ ; then will

$CD$  be a mean proportional between  $AD$  and  $DB$ ;

$AC$  a mean proportional between  $AB$  and  $AD$ ;

$BC$  a mean proportional between  $AB$  and  $BD$ .

Or,  $AD : CD :: CD : DB$ ; and  $AB : BC :: BC : BD$ ; and  $AB : AC :: AC : AD$ .



For,

For, the two triangles ABC, ADC, having the right angles at C and D equal, and the angle A common, have their third angles equal, and are equiangular (cor. 1, th. 17). In like manner, the two triangles ABC, BD, having the right angles at C and D equal, and the angle B common, have their third angles equal, and are equiangular.

Hence then, all the three triangles ABC, ADC, BDC, being equiangular, will have their like sides proportional (th. 84);

$$\text{viz. } AD : CD :: CD : DB;$$

$$\text{and } AB : AC :: AC : AD;$$

$$\text{and } AB : BC :: BC : BD.$$

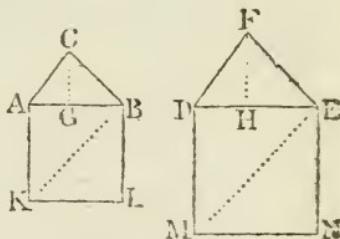
Q. E. D.

*Corol.* Because the angle in a semicircle is a right angle (th. 52), it follows, that if, from any point C in the periphery of the semicircle, a perpendicular be drawn to the diameter AB; and the two chords CA, CB, be drawn to the extremities of the diameter: then are AC, BC, CD, the mean proportionals as in this theorem, or (by th. 77),  $CD^2 = AD \cdot DB$ ;  $AC^2 = AB \cdot AD$ ; and  $BC^2 = AB \cdot BD$ .

## THEOREM LXXXVIII.

Equiangular or Similar Triangles, are to each other as the Squares of their Like Sides,

LET ABC, DEF, be two equiangular triangles, AB and DE being two homologous or like sides: then will the triangle ABC be to the triangle DEF, as the square of AB is to the square of DE, or as  $AB^2$  to  $DE^2$ .



For, let AL and DN be the squares on AB and DE; also draw their diagonals BK, EM, and the perpendiculars CG, FH, of the two triangles.

Then, since equiangular triangles have their like sides proportional (th. 84), in the two equiangular triangles ABC, DEF, the side AC : DF :: AB : DE; and in the two ACG, DFH, the side AC : DF :: CG : FH; therefore, by equality, CG : FH :: AB : DE, or CG : AB :: FH : DE.

But because triangles on equal bases are to each other as their altitudes, the triangles ABC, ABK, on the same base AB, are to each other, as their altitudes CG, AK, or AB; and

and the triangles DEF, DEM, on the same base DE, are as their altitudes FH, DM, or DE;

that is, triangle ABC : triangle ABK :: CG : AB,  
and triangle DEF : triangle DEM :: FH : DE.

But it has been shewn that CG : AB :: FH : DE;  
theref. of equality  $\triangle ABC : \triangle ABK :: \triangle DEF : \triangle DEM$ ,  
or alternately, as  $\triangle ABC : \triangle DEF :: \triangle ABK : \triangle DEM$ ,

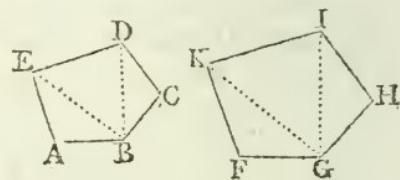
But the squares AL, DN, being the double of the triangles  
 $\triangle ABK$ ,  $\triangle DEM$ , have the same ratio with them;  
therefore the  $\triangle ABC : \triangle DEF :: \text{square } AL : \text{square } DN$ .

Q. E. D.

### THEOREM LXXXIX.

All Similar Figures are in Proportion to each other, as the Squares of their Like Sides.

LET ABCDE, FGHIK, be any two similar figures, the like sides being AB, FG, and BC, GH, and so on in the same order: then will the figure ABCDE be to the figure FGHIK, as the square of AB to the square of FG, or as AB<sup>2</sup> to FG<sup>2</sup>.



For, draw BE, BD, CK, GI, dividing the figures into an equal number of triangles, by lines from two equal angles, B and G.

The two figures being similar (by suppos'), they are equiangular, and have their like sides proportional (def. 67).

Then, since the angle A is = the angle F, and the sides AB, AE, proportional to the sides FG, FK, the triangles ABE, FGK, are equiangular (th. 86). In like manner, the two triangles BCD, CHI, having the angle C = the angle H, and the sides BC, CD, proportional to the sides GH, HI, are also equiangular. Also, if from the equal angles AED, FKI, there be taken the equal angles AEB, FGK, there will remain the equals BED, GKI; and if from the equal angles CDE, HIK, be taken away the equals CDB, HIG, there will remain the equals BDE, GIK; so that the two triangles BDE, GIK, having two angles equal, are also equiangular. Hence each triangle of the one figure, is equiangular with each corresponding triangle of the other.

But equiangular triangles are similar, and are proportional to the squares of their like sides (th. 88).

Therefore

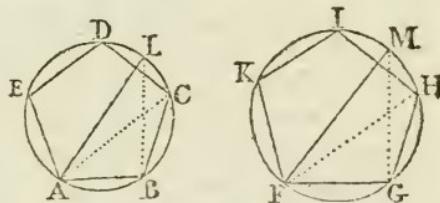
Therefore the  $\Delta ABE : \Delta FGK :: AB^2 : FG^2$ ,  
 and  $\Delta BCD : \Delta GHI :: BC^2 : GH^2$ ,  
 and  $\Delta BDE : \Delta GIK :: DE^2 : IK^2$ .

But as the two polygons are similar, their like sides are proportional, and consequently their squares also proportional; so that all the ratios  $AB$  to  $FG^2$ , and  $BC^2$  to  $GH^2$ , and  $DE^2$  to  $IK^2$ , are equal among themselves, and consequently the corresponding triangles also,  $ABE$  to  $FGK$ , and  $BCD$  to  $GHI$ , and  $BDE$  to  $GIK$ , have all the same ratio, viz. that of  $AB^2$  to  $FG^2$ : and hence all the antecedents, or the figure  $ABCDE$ , have to all the consequents, or the figure  $FGHIK$ , still the same ratio, viz. that of  $AB^2$  to  $FG^2$  (th. 72). Q. E. D.

## THEOREM XC.

Similar Polygons Inscribed in Circles, have their Like Sides, and also their Whole Perimeters, in the Same Ratio as the Diameters of the Circles in which they are inscribed.

LET  $ABCDE$ ,  $FGHIK$ , be two similar figures, inscribed in the circle whose diameters are  $AL$  and  $FM$ ; then will each side  $AB$ ,  $BC$ , &c, of the one figure, be to the like side  $GF$ ,  $GH$ , &c, of the other figure, or the whole perimeter  $AB + BC$ , &c, of the one figure, to the whole perimeter  $FG + GH$ , &c, of the other figure, as the diameter  $AL$  to the diameter  $FM$ .



For, draw the two corresponding diagonals  $AC$ ,  $FH$ , as also the lines  $BL$ ,  $GM$ . Then, since the polygons are similar, they are equiangular, and their like sides have the same ratio (def. 67); therefore the two triangles  $ABC$ ,  $FGH$ , have the angle  $B =$  the angle  $G$ , and the sides  $AB$ ,  $BC$ , proportional to the two sides  $FG$ ,  $GH$ , and consequently these two triangles are equiangular (th. 86), and have the angle  $ACB = FHG$ . But the angle  $ACB = ALB$ , standing on the same arc  $AB$ ; and the angle  $FHG = FMG$ , standing on the same arc  $FG$ ; therefore the angle  $ALB = FMG$  (ax. 1). And since the angle  $ABL = FGM$ , being both right angles, because in a semicircle; therefore the two triangles  $ABL$ ,  $FGM$ , having two angles equal, are equiangular; and consequently their like

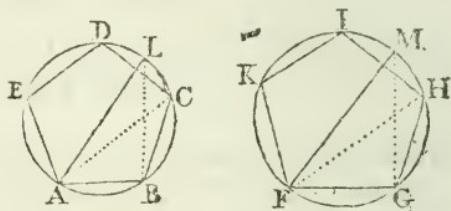
like sides are proportional (th. 84); hence  $AB : FG ::$  the diameter  $AL$  : the diameter  $FM$ .

In like manner, each side  $BC$ ,  $CD$ , &c, has to each side  $GH$ ,  $HI$ , &c, the same ratio of  $AL$  to  $FM$ ; and consequently the sums of them are still in the same ratio; viz,  $AB + BC + CD, \&c : FG + GH + HI, \&c ::$  the diam.  $AL$  : the diam.  $FM$  (th. 72). Q. E. D.

### THEOREM XCII.

Similar Polygons Inscribed in Circles, are in Proportion to each other as the Squares of the Diameters of those Circles.

LET  $ABCDE$ ,  $FGHIK$ , be two similar figures, inscribed in the circles whose diameters are  $AL$  and  $FM$ ; then the surface of the polygon  $ABCDE$  will be to the surface of the polygon  $FGHIK$ , as  $AL^2$  to  $FM^2$ .



For, the figures, being similar, are to each other as the squares of their like sides,  $AB$  to  $FG^2$  (th. 83). But, by the last theorem, the sides  $AB$ ,  $FG$ , are as the diameters  $AL$ ,  $FM$ ; and therefore the squares of the sides  $AB$  to  $FG^2$ , as the squares of the diameters  $AL^2$  to  $FM^2$  (th. 74). Consequently the polygons  $ABCDE$ ,  $FGHIK$ , are also to each other as the squares of the diameters  $AL^2$  to  $FM^2$  (ax. 1).

Q. E. D.

### THEOREM XCIII.

The Circumferences of Circles are in Proportion to each other as their Diameters.

LET  $d$ ,  $d$ , denote the diameters of two circles, and  $c$ ,  $c$ , their circumferences;

then will  $d : d :: c : c$ , or  $d : c :: d : c$ .

For (by theor. 90), similar polygons inscribed in circles have their perimeters in the same ratio as the diameters of those circles.

Now, as this property belongs to all polygons, whatever the number of the sides may be; conceive the number of the sides to be indefinitely great, and the length of each indefinitely small, till they coincide with the circumference of the

the

the circle, and be equal to it, indefinitely near. Then the perimeter of the polygon of an infinite number of sides, is the same thing as the circumference of the circle. Hence it appears that the circumferences of the circles, being the same as the perimeters of such polygons, are to each other in the same proportion as the diameters of the circles. Q. E. D.

## THEOREM XCIII.

The Areas or Spaces of Circles, are to each other as the Squares of their Diameters, or of their Radii.

LET  $A, a$ , be the areas or spaces of two circles, and  $b, d$ , their diameters; then  $A : a :: b^2 : d^2$ .

For (by theorem 91) similar polygons inscribed in circles are to each other as the squares of the diameters of the circles.

Hence, conceiving the number of the sides of the polygons to be increased more and more, or the length of the sides to become less and less, the polygon approaches nearer and nearer to the circle, till at length, by an infinite approach, they coincide and become in effect equal; and then it follows, that the spaces of the circles, which are the same as of the polygons, will be to each other as the squares of the diameters of the circles. Q. E. D.

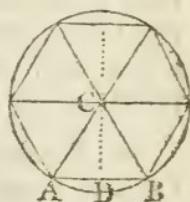
*Corol.* The spaces of circles are also to each other as the squares of the circumferences; since the circumferences are in the same ratio as the diameters, (by theorem 92).

## THEOREM XCIV.

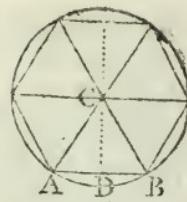
Every Circle is Equal to the Rectangle of its Radius and a Right Line equal to Half its Circumference.

CONCEIVE a regular polygon to be inscribed in the circle; and radii drawn to all the angular points, dividing it into as many equal triangles as the polygon has sides, one of which is  $ABC$ , of which the altitude is the perpendicular  $CD$  from the centre to the base  $AB$ .

Then the triangle  $ABC$ , being equal to half a rectangle of equal base and altitude (th. 26), is equal to half the rectangle of the base  $AB$  and altitude  $CD$ , or equal



equal to the rectangle of the altitude  $CD$  and half the base  $AB$ ; consequently the whole polygon, or all the triangles added together which compose it, is equal to the rectangle of the common altitude  $CD$ , and the halves of all the sides, or the half of the perimeter of the polygon.



Now, conceive the number of sides of the polygon to be indefinitely increased; then will its perimeter coincide with the circumference of the circle, and consequently the altitude  $CD$  will become equal to the radius, and the whole polygon equal to the circle. Consequently the space of the circle, or of the polygon in that state, is equal to the rectangle of the radius and half the circumference. Q. E. D.

## OF PLANES AND SOLIDS.

### DEFINITIONS.

**DEF. 88.** The Common Section of two Planes, is the line in which they meet, to cut each other.

89. A Right Line is Perpendicular to a Plane, when it is perpendicular to every right line in that plane which meets it.

90. One Plane is Perpendicular to Another, when every right line in the one, which is perpendicular to the line of their common section, is perpendicular to the other.

91. The Inclination of one Plane to another, or the angle they form between them, is the angle contained by two right lines, drawn from any point in the common section, and at right angles to the same, one of these lines in each plane.

92. Parallel Planes, are such as being produced ever so far both ways will never meet, or which are every where at an equal perpendicular distance.

93. A Solid Angle, is that which is made by three or more plane angles meeting each other in the same point.

94. Similar

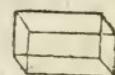
94. Similar Solids, contained by plane figures, are such as have all their solid angles equal, each to each, and are bounded by the same number of similar planes, alike placed.

95. A Prism, is a solid whose ends are parallel, equal, and like plane figures, and its sides, connecting those ends, are parallelograms.

96. A Prism takes particular names according to the figure of its base or ends, whether triangular, square, rectangular, pentagonal, hexagonal, &c.

97. An Upright Prism, is that which has the planes of the sides perpendicular to the planes of the ends or base.

98. A Parallelopiped, or Parallelopipedon, is a prism bounded by six parallelograms, every opposite two of which are equal, alike, and parallel.



99. A Rectangular Parallelopipedon, is that whose bounding planes are all rectangles, which are perpendicular to each other.

100. A Cube, is a square prism, being bounded by six equal square sides or faces, and are perpendicular to each other.



101. A Cylinder is a round prism, having circles for its ends; and is conceived to be formed by the rotation of a right line about the circumferences of two equal and parallel circles, always parallel to the axis.



102. The Axis of a Cylinder, is the right line joining the centres of the two parallel circles, about which the figure is described.

103. A Pyramid, is a solid, whose base is any right-lined plane figure, and its sides triangles, having all their vertices meeting together in a point above the base, called the Vertex of the pyramid.



104. A pyramid, like the prism, takes particular names from the figure of the base.

105. A Cone, is a round pyramid, having a circular base, and is conceived to be generated by the rotation of a right line about the circumference of a circle, one end of which is fixed at a point above the plane of that circle.



106. The Axis of a cone, is the right line joining the vertex, or fixed point, and the centre of the circle about which the figure is described.

107. Similar Cones and Cylinders, are such as have their altitudes and the diameters of their bases proportional.

108. A Sphere, is a solid bounded by one convex surface, which is every where equally distant from a certain point within, called the Centre. It is conceived to be generated by the rotation of a semicircle about its diameter, which remains fixed.

109. The Axis of a Sphere, is the right line about which the semicircle revolves; and the centre is the same as that of the revolving semicircle.

110. The Diameter of a Sphere, is any right line passing through the centre, and terminated both ways by the surface.

111. The Altitude of a Solid, is the perpendicular drawn from the vertex to the opposite side or base.

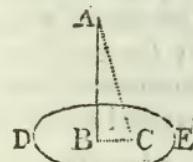
#### THEOREM XCV.

A Perpendicular is the Shortest Line which can be drawn from any Point to a Plane.

LET  $AB$  be perpendicular to the plane  $DE$ ; then any other line, as  $AC$ , drawn from the same point  $A$  to the plane, will be longer than the line  $AB$ .

In the plane draw the line  $BC$ , joining the points  $B, C$ .

Then, because the line  $AB$  is perpendicular to the plane  $DE$ , the angle  $B$  is a right angle (def. 90), and consequently greater than the angle  $C$ ; therefore the line  $AB$ , opposite to the less angle, is less than any other line  $AC$  opposite the greater angle, (th. 21). Q. E. D.



#### THEOREM XCVI.

A Perpendicular Measures the Distance of any Point from a Plane.

THE distance of one point from another is measured by a right line joining them, because this is the shortest line which can be drawn from one point to another. So, also, the distance from a point to a line, is measured by a perpendicular, because this line is the shortest which can be drawn from

from the point to the line. In like manner, the distance from a point to a plane, must be measured by a perpendicular drawn from that point to the plane, because this is the shortest line which can be drawn from the point to the plane.

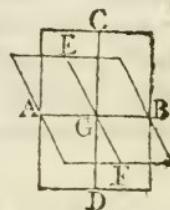
## THEOREM XCVII.

The Common Section of Two Planes, is a Right Line,

LET  $ACBDA$ ,  $AEBFA$ , be two planes cutting each other, and  $A$ ,  $B$ , two points in which the two planes meet; drawing the line  $AB$ , this line will be the common intersection of the two planes.

For, because the right line  $AB$  touches the two planes in the points  $A$  and  $B$ , it touches them in all other points (def. 20): this line is therefore common to the two planes. That is, the common intersection of the two planes is a right line.

Q. E. D.

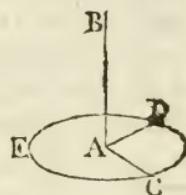


## THEOREM XCVIII.

If a Line be Perpendicular to two other Lines, at their Common Point of Meeting; it will be Perpendicular to the Plane of those Lines.

LET the line  $AB$  make right angles with the lines  $AC$ ,  $AD$ ; it will be perpendicular to the plane  $CDE$  which passes through these lines.

If the line  $AB$  were not perpendicular to the plane  $CDE$ , another plane might pass through the point  $A$ , to which the line  $AB$  would be perpendicular. But this is impossible; for, since the angles  $BAC$ ,  $BAD$ , are right angles, this other plane must pass through the points  $C$ ,  $D$ . Hence, this plane passing through the two points  $A$ ,  $C$ , of the line  $AC$ , and through the two points  $A$ ,  $D$ , of the line  $AD$ , it will pass through both these two lines, and therefore be the same plane with the former. Q. E. D.

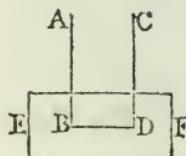


## THEOREM XCIX.

If Two Lines be Perpendicular to the Same Plane, they will be Parallel to each other.

LET the two lines  $AB$ ,  $CD$ , be both of them perpendicular to the same plane  $EBDF$ ; then will  $AB$  be parallel to  $CD$ .

For, join  $B$ ,  $D$ , by the line  $BD$  in the plane. Then, because the lines  $AB$ ,  $CD$ , are perpendicular to the plane  $EF$ , they are both perpendicular to the line  $BD$  (def. 90) in that plane. And because  $AB$  and  $CD$  are both perpendicular to the same line  $BD$ , they are parallel to each other (corol. th. 13).



Q. E. D.

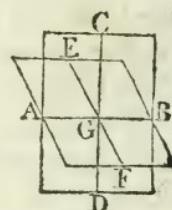
*Corol.* If two lines be parallel, and if one of them be perpendicular to any plane, the other will also be perpendicular to the same plane.

## THEOREM C.

If Two Planes Cut each other at Right Angles, and a Line be drawn in one of the Planes Perpendicular to their Common Intersection, it will be Perpendicular to the other Plane.

LET the two planes  $ACBD$ ,  $AEBF$ , cut each other at right angles; and the line  $CG$  perpendicular to their common section  $AB$ ; then will  $CG$  be also perpendicular to the other plane  $AEBF$ .

For, draw  $EG$  perpendicular to  $AB$ . Then, because the two lines  $GC$ ,  $GE$ , are perpendicular to the common intersection  $AB$ , the angle  $CGE$  is the angle of inclination of the two planes (def. 92). But since the two planes cut each other perpendicularly, the angle of inclination  $CGE$  is a right angle. And since the line  $CG$  is perpendicular to the two lines  $GA$ ,  $GE$ , in the plane  $AEBF$ , it is therefore perpendicular to that plane (th. 98). Q. E. D.



## THEOREM

## THEOREM CI.

If one Plane Meet another Plane; it will make Angles with that other Plane, which are together Equal to Two Right Angles.

LET the plane ACBD meet the plane AEBF; these planes make with each other two angles whose sum is equal to two right angles.

For, through any point G, in the common section AB, draw CD, EF, perpendicular to AB. Then, the line CG makes with EF two angles together equal to two right angles. But these two angles are (by def. 92) the angles of inclination of the two planes. Therefore the two planes make angles with each other, which are together equal to two right angles.

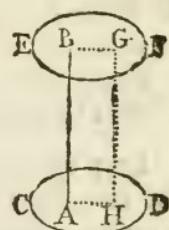
*Corol.* In like manner, it may be demonstrated, that planes which intersect, have their vertical or opposite angles equal; also, that parallel planes have their alternate angles equal; and so on, as in parallel lines.

## THEOREM CII.

If Two Planes be Parallel to each other; a Line which is Perpendicular to one of the Planes, will also be Perpendicular to the other.

LET the two planes CD, EF, be parallel, and let the line AB be perpendicular to the plane CD; then shall it also be perpendicular to the other plane EF.

For, from any point G, in the plane EF, draw GH perpendicular to the plane CD, and draw AH, BG.



Then, because BA, GH, are both perpendicular to the plane CD, the angles A and H are both right angles. And because the planes CD, EF, are parallel, the perpendiculars BA, GH, are equal (def. 93). Hence it follows that the lines BG, AH, are parallel (def. 9). And the line AB being perpendicular to the line AH, is also perpendicular to the parallel line BG (cor. th. 12).

In like manner, it is proved, that the line AB is perpendicular to all other lines which can be drawn from the point B

in the plane  $EF$ . Therefore the line  $AB$  is perpendicular to the whole plane  $EF$  (def. 90). Q. E. D.

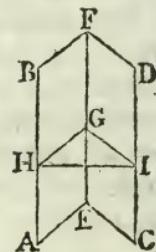
## THEOREM CIII.

If Two Lines be Parallel to a Third Line, though not in the same Plane with it; they will be Parallel to each other.

LET the lines  $AB$ ,  $CD$ , be each of them parallel to the third line  $EF$ , though not in the same plane with it; then will  $AB$  be parallel to  $CD$ .

For, from any point  $G$  in the line  $EF$ , let  $GH$ ,  $GI$ , be each perpendicular to  $EF$ , in the planes  $EB$ ,  $ED$ , of the proposed parallels.

Then, since the line  $EF$  is perpendicular to the two lines  $GH$ ,  $GI$ , it is perpendicular to the plane  $GH$  of those lines (th. 98). And because  $EF$  is perpendicular to the plane  $GH$ , its parallel  $AB$  is also perpendicular to that plane (th. 99, cor.) For the same reason, the line  $CD$  is perpendicular to the same plane  $GH$ . Hence, because the two lines  $AB$ ,  $CD$ , are perpendicular to the same plane, these two lines are parallel (th. 99). Q. E. D.



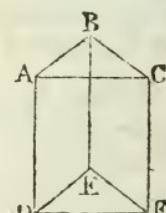
## THEOREM CIV.

If Two Lines that meet each other, be Parallel to Two other Lines that meet each other, though not in the same Plane with them; the Angles contained by those Lines will be equal.

LET the two lines  $AB$ ,  $BC$ , be parallel to the two lines  $DE$ ,  $EF$ ; then will the angle  $ABC$  be equal to the angle  $DEF$ .

For, make the lines  $AB$ ,  $BC$ ,  $DE$ ,  $EF$ , all equal to each other; and join  $AC$ ,  $DF$ ,  $AD$ ,  $BE$ ,  $CF$ .

Then, the lines  $AD$ ,  $BE$ , joining the equal and parallel lines  $AB$ ,  $DE$ , are equal and parallel (th. 24). For the same reason,  $CF$ ,  $BE$ , are equal and parallel. Therefore  $AD$ ,  $CF$ , are equal and parallel (th. 15); and consequently also  $AC$ ,  $DF$  (th. 24). Hence, the two triangles  $ABC$ ,  $DEF$ , having all their sides equal, each



each to each, have their angles also equal, and consequently the angle  $A B C =$  the angle  $D E F$ . Q. E. D.

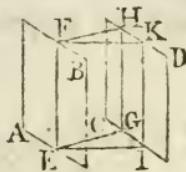
## THEOREM CV.

The Sections made by a Plane cutting two other Parallel Planes, are also Parallel to each other.

LET the two parallel planes  $AB, CD$ , be cut by the third plane  $EFGH$ , in the lines  $EF, GH$ ; these two sections  $EF, GH$ , will be parallel.

Suppose  $EG, FH$ , be drawn parallel to each other in the plane  $EFGH$ ; also let  $EI, FK$ , be perpendicular to the plane  $CD$ ; and let  $IG, KH$ , be joined.

Then  $EG, FH$ , being parallels, and  $EI, FK$ , being both perpendicular to the plane  $CD$ , are also parallel to each other (th. 99); consequently the angle  $HFK$  is equal to the angle  $GEI$  (th. 104). But the angle  $FKH$  is also equal the angle  $FIG$ , being both right angles; therefore the two triangles are equiangular (cor. 1, th. 17); and the sides  $FK, EI$ , being the equal distances between the parallel planes (def. 93), it follows that the sides  $FH, EG$ , are also equal (th. 2). But these two lines are parallel (by suppos.), as well as equal; consequently the two lines  $EF, GH$ , joining those equal parallels, are also parallel (th. 24). Q. E. D.

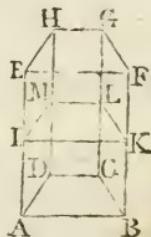


## THEOREM CVI.

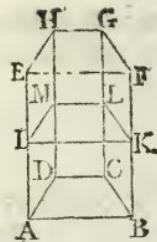
If a Prism be cut by a Plane Parallel to its Base, the Section will be Equal and Like to the Base.

LET  $AG$  be any prism, and  $IL$  a plane parallel to the base  $AC$ ; then will the plane  $IL$  be equal and like to the base  $AC$ , or the two planes will have all their sides and all their angles equal.

For, the two planes  $AC, IL$ , being parallel, by hypothesis; and two parallel planes, cut by a third plane, having parallel sections (th. 105); therefore  $IK$  is parallel to  $AB$ , and  $KL$  to  $BC$ , and  $LM$  to  $CD$ , and  $IM$  to  $AD$ . But  $AI$  and  $BK$  are parallels (by def. 96); consequently  $AK$  is a parallelogram; and the opposite sides  $AB, IK$ , are equal (th. 22). In like manner,



it is shewn that  $KL = BC$ , and  $LM = CD$ , and  $IM = AD$ , or the two planes  $AC, IL$ , are mutually equilateral. But these two planes, having their corresponding sides parallel, have the angles contained by them also equal (th. 104), namely, the angle  $A =$  the angle  $I$ , the angle  $B =$  the angle  $K$ , the angle  $C =$  the angle  $L$ , and the angle  $D =$  the angle  $M$ . So that the two planes  $AC, IL$ , have all their corresponding sides and angles equal, or are equal and like. Q. E. D.



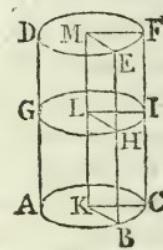
## THEOREM CVII.

If a Cylinder be cut by a Plane Parallel to its Base, the Section will be a Circle, Equal to the Base.

LET AF be a cylinder, and GHI any section parallel to the base ABC; then will GHI be a circle, equal to ABC.

For, let the planes KE, KF, pass through the axis of the cylinder MK, and meet the section GHI in the three points H, I, L; and join the points as in the figure.

Then, since  $KL, CI$ , are parallel (by def. 102); and the plane  $KI$ , meeting the two parallel planes  $ABC, GHI$ , makes the two sections  $KC, LI$ , parallel (th. 105); the figure  $KLIC$  is therefore a parallelogram, and consequently has the opposite sides  $LI, KC$ , equal, where  $KC$  is a radius of the circular base.



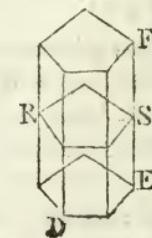
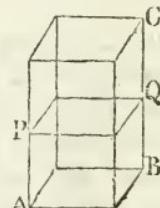
In like manner, it is shewn that  $LH$  is equal to the radius  $KB$ ; and that any other lines, drawn from the point  $L$  to the circumference of the section  $GHI$ , are all equal to radii of the base; consequently  $GHI$  is a circle, and equal to  $AEC$ .

Q. E. D.

## THEOREM CVIII.

All Prisms and Cylinders, of Equal Bases and Altitudes, are Equal to each other.

LET AC, DF, be two prisms, and a cylinder, upon equal bases AB, DE, and having equal altitudes BC and EF; then will the solids AC, DF, be equal.



For, let  $PQ, RS$ , be any

any two sections parallel to the bases, and equidistant from them. Then, by the last two theorems, the section  $PQ$  is equal to the base  $AB$ , and the section  $RS$  equal the base  $DE$ . But the bases  $AB$ ,  $DE$ , are equal, by the hypothesis; therefore the sections  $PQ$ ,  $RS$ , are equal also. In like manner, it may be shewn, that any other corresponding sections are equal to one another.

Since then every section in the prism  $AC$ , is equal to its corresponding section in the prism or cylinder  $DF$ , the prisms and cylinder themselves, which are composed of an equal number of all those sections, must also be equal. Q. E. D.

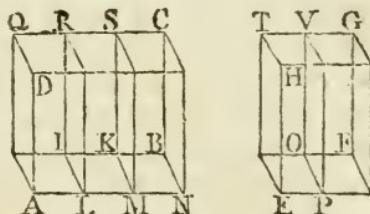
*Corol.* Every prism, or cylinder, is equal to a rectangular parallelopipedon, of an equal base and altitude.

### THEOREM CIX.

Rectangular Parallelopipedons, of Equal Altitudes, have to each other the same Proportion as their Bases.

LET  $AC$ ,  $EG$ , be two rectangular parallelopipedons, having the equal altitudes  $AD$ ,  $EH$ ; then will the solid  $AC$  be to the solid  $EG$ , as the base  $AB$  is to the base  $EF$ .

For, let the proportion of the base  $AB$  to the base  $EF$ , be that of any one number  $m$  (3) to any other number  $n$  (2). And conceive  $AB$  to be divided into  $m$  equal parts, or rectangles,  $AI$ ,  $LK$ ,  $MB$  (by dividing  $AN$  into that number of equal parts, and drawing  $IL$ ,  $KM$ , parallel to  $BN$ ). And let  $EF$  be divided, in like manner, into  $n$  equal parts, or rectangles,  $EO$ ,  $PF$ : all of these parts of both bases being mutually equal among themselves. And through the lines of division let the plane sections  $LR$ ,  $MS$ ,  $PV$ , pass parallel to  $AQ$ ,  $ET$ .



Then, the parallelopipedons  $AR$ ,  $LS$ ,  $MC$ ,  $EV$ ,  $PT$ , are all equal, having equal bases and altitudes. Therefore the solid  $AC$  is to the solid  $EG$ , as the number of parts in the former to the number of equal parts in the latter; or as the number of parts in  $AB$  to the number of equal parts in  $EF$ , that is, as the base  $AB$  to the base  $EF$ . Q. E. D.

*Corol.* From this theorem, and the corollary to the last, it appears, that all prisms and cylinders of equal altitudes, are to

to each other as their bases; every prism and cylinder being equal to a rectangular parallelopipedon of an equal base and altitude.

## THEOREM CX.

Rectangular Parallelopipeds, of Equal Bases, are in Proportion to each other as their Altitudes.

LET  $AB, CD$ , be two rectangular parallelopipeds standing on the equal bases  $AE, CF$ ; then will the solid  $AB$  be to the solid  $CD$ , as the altitude  $EB$  is to the altitude  $FD$ .

For, let  $AG$  be a rectangular parallelopipedon on the base  $AE$ , and its altitude  $EG$  equal to the altitude  $FD$  of the solid  $CD$ .

Then  $AG$  and  $CD$  are equal, being prisms of equal bases and altitudes. But if  $HB, HG$ , be considered as bases, the solids  $AB, AG$ , of equal altitude  $AH$ , will be to each other as those bases  $HB, HG$ . But these bases  $HB, HG$ , being parallelograms of equal altitude  $HE$ , are to each other as their bases  $EB, EG$ ; therefore the two prisms  $AB, AG$ , are to each other as the lines  $EB, EG$ . But  $AG$  is equal to  $CD$ , and  $EG$  equal to  $FD$ ; consequently the prisms  $AB, CD$ , are to each other as their altitudes  $EB, FD$ ; that is, - - -  $AB : CD :: EB : FD$ . Q. E. D.

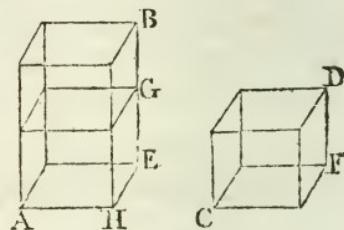
*Corol.* 1. From this theorem, and the corollary to theorem 108, it appears, that all prisms and cylinders, of equal bases, are to one another as their altitudes.

*Corol.* 2. Because, by corollary 1, prisms and cylinders are as their altitudes, when their bases are equal. And, by the corollary to the last theorem, they are as their bases, when their altitudes are equal. Therefore, universally, when neither are equal, they are to one another as the product of their bases and altitudes. And hence also these products are the proper numeral measures of their quantities or magnitudes.

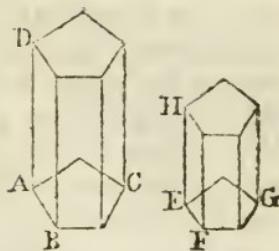
## THEOREM CXI.

Similar Prisms and Cylinders are to each other as the Cubes of their Altitudes, or of any other Like Linear Dimensions.

LET  $ABCD, EFGH$ , be two similar prisms; then will the prism  $CD$  be to the prism  $GH$ , as  $AB^3$  to  $EF^3$  or  $AD^3$  to  $EH^3$ .



For the solids are to each other as the product of their bases and altitudes (th. 110, cor. 2), that is, as  $AC \cdot AD$  to  $EG \cdot EH$ . But the bases, being similar planes, are to each other as the squares of their like sides, that is,  $AC$  to  $EG$  as  $AB^2$  to  $EF^2$ ; therefore the solid  $CD$  is to the solid  $GH$  as  $AB^2 \cdot AD$  to  $EF^2 \cdot EH$ . But  $BD$  and  $FH$ , being similar planes, have their like sides proportional, that is,  $AB : EF :: AD : EH$ , - - - - or  $AB^2 : EF^2 :: AD^2 : EH^2$ : therefore  $AB^2 \cdot AD : EF^2 \cdot EH :: AB^3 : EH^3$ , or ::  $AD^3 : EH^3$ ; conseq. the solid  $CD$  : solid  $GH :: AB^3 : EF^3 :: AD^3 : EH^3$ . Q. E. D.



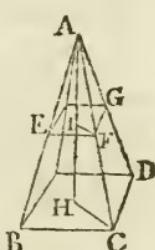
## THEOREM CXII.

In a Pyramid, a Section Parallel to the Base is similar to the Base; and these two planes are to each other as the Squares of their Distance from the Vertex.

LET  $ABCD$  be a pyramid, and  $EFG$  a section parallel to the base  $BCD$ , also  $AH$  a line perpendicular to the two planes at  $H$  and  $I$ : then will  $BD$ ,  $EG$ , be two similar planes, and the plane  $BD$  will be to the plane  $EG$  as  $AH^2$  to  $AI^2$ .

For, join  $CH$ ,  $FI$ . Then, because a plane cutting two parallel planes, makes parallel sections (th. 105), therefore the plane  $ABC$ , meeting the two parallel planes  $BD$ ,  $EG$ , makes the sections  $BC$ ,  $EF$ , parallel: In like manner, the plane  $ACD$  makes the sections  $CD$ ,  $FG$ , parallel. Again, because two pair of parallel lines makes equal angles (th. 104), the two  $EF$ ,  $FG$ , which are parallel to  $BC$ ,  $CD$ , make the angle  $EFG$  equal the angle  $BCD$ . And, in like manner, it is shewn, that each angle in the plane  $EG$  is equal to each angle in the plane  $BD$ , and consequently those two planes are equiangular.

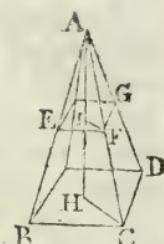
Again, the three lines  $AB$ ,  $AC$ ,  $AD$ , making with the parallels  $BC$ ,  $EF$ , and  $CD$ ,  $FG$ , equal angles (th. 14), and the angles at  $A$  being common, the two triangles  $AEC$ ,  $AEF$ , are equiangular, as also the two triangles  $ACD$ ,  $AFG$ , and have therefore their like sides proportional, namely, - - - -



$AC : AF :: BC : EF :: CD : FG$ . And, in like manner, it may be shewn, that all the line in the plane  $EG$  are proportional to all the corresponding ones in the base  $BD$ . Hence these two planes, having their angles equal and their sides proportional, are similar, by def. 68.

But, similar planes being to each other as the squares of their like sides, the plane  $BD : EG :: BC^2 : EF^2$ , or  $:: AC^2 : AF^2$ , by what is shewn above. Also, the two triangles  $AHC$ ,  $AIF$ , having the angles  $H$  and  $I$  right ones (th. 98), and the angle  $A$  common, are equiangular, and have therefore their like sides proportional, namely,  $AC : AF :: AH : AI$ , or  $AC^2 : AF^2 :: AH^2 : AI^2$ . Consequently the two planes  $BD$ ,  $EG$ , which are as the former squares  $AC^2$ ,  $AF^2$ , will be also as the latter squares  $AH^2$ ,  $AI^2$ , that is, - - - - -

Q. E. D.



## THEOREM CXIII.

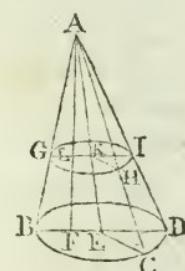
In a Cone, any Section Parallel to the Base is a Circle; and this Section is to the Base as the Squares of their Distances from the Vertex.

LET  $ABCD$  be a cone, and  $GHI$  a section parallel to the base  $BCD$ ; then will  $GHI$  be a circle, and  $BCD$ ,  $GHI$ , will be to each other as the squares of their distances from the vertex.

For, draw  $ALF$  perpendicular to the two parallel planes; and let the planes  $ACE$ ,  $ADE$ , pass through the axis of the cone  $AKE$ , meeting the section in the three points  $H$ ,  $I$ ,  $K$ .

Then, since the section  $GHI$  is parallel to the base  $BCD$ , and the planes  $CK$ ,  $DK$ , meet them,  $HK$  is parallel to  $CE$ , and  $IK$  to  $DE$  (th. 105). And because the triangles formed by these lines are equiangular,  $KH : EC :: AK : AE :: KI : ED$ . But  $EC$  is equal to  $ED$ , being radii of the same circle; therefore  $KI$  is also equal to  $KH$ . And the same may be shewn of any other lines drawn from the point  $K$  to the perimeter of the section  $GHI$ ; which is therefore a circle (def. 44).

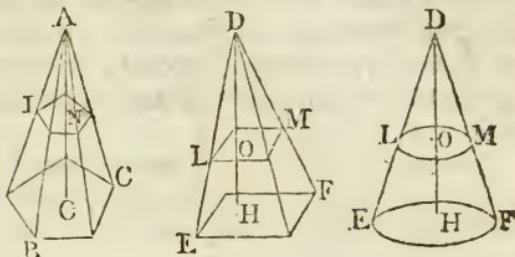
Again, by similar triangles,  $AL : AF :: AK : AE$  or  $:: KI : ED$ , hence  $AL^2 : AF^2 :: KI^2 : ED^2$ ; but  $KI^2 : ED^2 ::$  circle  $GHI$  : circle  $BCD$  (th. 93); therefore  $AL^2 : AF^2 ::$  circle  $GHI$  : circle  $BCD$ . Q. E. D.



## THEOREM CXIV.

All Pyramids, and Cones, of Equal Bases and Altitudes, are Equal to one another.

LET ABC, DEF, be any pyramids and cone, of equal bases BC, EF, and equal altitudes AG, DH: then will the pyramids and cone ABC and DEF, be equal.



For, parallel to the bases, and at equal distances AN, DO, from the vertices, suppose the planes IK, LM, to be drawn.

Then, by the two preceding theorems, - - - - -

$$DO^2 DH^2 :: LM : EF, \text{ and}$$

$$AN^2 AG^2 :: IK : BC.$$

But since  $AN^2, AG^2$ , are equal to  $DO^2, DH^2$ , therefore  $IK : BC :: LM : EF$ . But  $BC$  is equal to  $EF$ , by hypothesis; therefore  $IK$  is also equal to  $LM$ .

In the same manner it is shewn, that any other sections, at equal distance from the vertex, are equal to each other.

Since then, every section in the cone, is equal to the corresponding section in the pyramids, and the heights are equal, the solids AEC, DEF, composed of all those sections, must be equal also. Q. E. D.

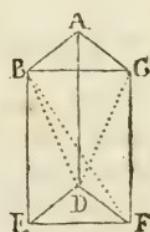
## THEOREM CXV.

Every Pyramid of a Triangular Base, is the Third Part of a Prism of the Same Base and Altitude.

LET ABCDEF be a prism, and BDEF a pyramid, on the same triangular base DEF: then will the pyramid BDEF be a third part of the prism ABCDEF.

For, in the planes of the three sides of the prism, draw the diagonals BF, BD, CD. Then the two planes BDF, BCD, divide the whole prism into the three pyramids BDEF, DABC, DCBF, which are proved to be all equal to one another, as follows.

Since the opposite ends of the prism are equal to each other, the pyramid whose base is ABC and vertex D, is equal to the pyramid



pyramid whose base is DEF and vertex B (th. 114), being pyramids of equal base and altitude.

But the latter pyramid, whose base is DEF and vertex B, is the same solid as the pyramid whose base is BEF and vertex D, and this is equal to the third pyramid whose base is BCF and vertex D, being pyramids of the same altitude and equal bases BEF, BCF.

Consequently all the three pyramids, which compose the prism, are equal to each other, and each pyramid is the third part of the prism, or the prism is triple of the pyramid. Q. E. D.

*Corol.* 1. Every pyramid, whatever its figure may be, is the third part of a prism of the same base and altitude; since the base of the prism, whatever be its figure, may be divided into triangles, and the whole solid into triangular prisms and pyramids.

*Corol.* 2. Any cone is the third part of a cylinder, or of a prism, of equal base and altitude; since it has been proved that a cylinder is equal to a prism, and a cone equal to a pyramid, of equal base and altitude.

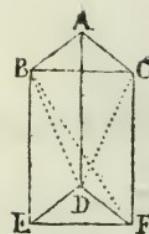
*Scholium.* Whatever has been demonstrated of the proportionality of prisms, or cylinders, holds equally true of pyramids, or cones; the former being always triple the latter; viz. that similar pyramids or cones, are as the cubes of their like linear sides, or diameters, or altitudes, &c. And the same for all similar solids whatever, viz. that they are in proportion to each other, as the cubes of their like linear dimensions, since they are composed of pyramids every way similar.

#### THEOREM CXVI.

If a Sphere be cut by a Plane, the Section will be a Circle.

LET the sphere AEBF be cut by the plane ADB; then will the section ADB be a circle.

Draw the chord AB, or diameter of the section; perpendicular to which, or to the section ADB, draw the axis of the sphere ECGF, through the centre c, which will bisect the chord AB in the point G (th. 41). Also, join CA, CB;



and

and draw  $CD$ ,  $CD$ , to any point  $D$  in the perimeter of the section  $ADB$ .

Then, because  $CG$  is perpendicular to the plane  $ADB$ , it is perpendicular both to  $GA$  and  $GD$  (def 90). So that  $CGA$ ,  $CGD$  are two right-angled triangles, having the perpendicular  $CG$  common, and the two hypotenuses  $CA$ ,  $CD$ , equal, being both radii of the sphere; therefore the third sides  $GA$ ,  $GD$ , are also equal (cor. 2, th. 34). In like manner, it is shewn, that any other line drawn from the centre  $G$  to the circumference of the section  $ADB$ , is equal to  $GA$  or  $GB$ ; consequently that section is a circle.

*Corol.* 1. The centre of every section of a sphere is always in a diameter of the sphere.

*Corol.* 2. The section through the centre, is a circle having the same centre and diameter as the sphere, and is called a great circle of the sphere; the other plane sections being little circles.

### THEOREM CXVII.

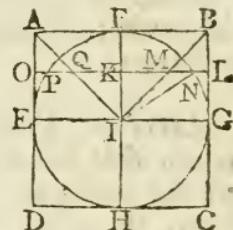
Every Sphere is Two-Thirds of its Circumscribing Cylinder.

LET  $ABCD$  be a cylinder, circumscribing the sphere  $EFGH$ ; then will the sphere  $EFGH$  be two-thirds of the cylinder  $ABCD$ .

For, let the plane  $AC$  be a section of the sphere and cylinder through the centre  $I$ . Join  $AI$ ,  $BI$ . Also, let  $FIH$  be parallel to  $AD$  or  $BC$ , and  $EIG$  and  $KL$  parallel to  $AB$  or  $DC$  the base of the cylinder, the latter line  $KL$  meeting  $BI$  in  $M$ , and the circular section of the sphere in  $N$ .

Then, if the whole plane  $HFEC$  be conceived to revolve about the line  $HF$  as an axis, the square  $FG$  will describe a cylinder  $AG$ , the quadrant  $IFG$  will describe a hemisphere  $EFG$ , and the triangle  $IFB$  will describe a cone  $IAB$ . Also, in the rotation, the three lines or parts  $KL$ ,  $KN$ ,  $KM$ , as radii, will describe corresponding circular sections of those solids, namely,  $KL$  a section of the cylinder,  $KN$  a section of the sphere, and  $KM$  a section of the cone.

Now,  $FB$  being equal to  $FI$  or  $IG$ , and  $KL$  parallel to  $FB$ , by similar triangles  $IKL$  is equal to  $KMN$  (th. 82). And since, in the right-angled triangle  $IKN$ ,  $IN^2$  is equal to  $IK^2 + KN^2$  (th. 34); and because  $KL$  is equal to the radius  $IG$  or



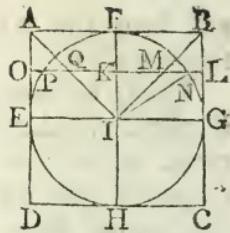
or  $IN = KM$ , therefore  $KL^2$  is equal to  $KM^2 + KN^2$ , or the square of the longest radius, of the said circular sections, is equal to the sum of the squares of the two others. And because circles are to each other as the squares of their diameters, or of their radii, therefore the circle described by  $KL$  is equal to both the circles described by  $KM$  and  $KN$ , or the section of the cylinder is equal to the corresponding sections of the sphere and cone. And as this is always the case in every parallel position of  $KL$ , it follows, that the cylinder  $EB$ , which is composed of all the former sections, is equal to the hemisphere  $EFG$  and cone  $IAB$ , which are composed of all the latter sections.

But the cone  $IAB$  is a third part of the cylinder  $EB$  (cor. 2, th. 115); consequently the hemisphere  $EFG$  is equal to the remaining two-thirds; or the whole sphere  $EFGH$  equal to two-thirds of the whole cylinder  $ABCD$ . Q. E. D.

*Corol.* 1. A cone, hemisphere, and cylinder, of the same base and altitude, are to each other as the numbers 1, 2, 3.

*Corol.* 2. All spheres are to each other as the cubes of their diameters; all these being like parts of their circumscribing cylinders.

*Corol.* 3. From the foregoing demonstration it also appears, that the spherical zone or frustum  $EGNP$ , is equal to the difference between the cylinder  $EGLO$  and the cone  $IMQ$ , all of the same common height  $IK$ . And that the spherical segment  $PFN$ , is equal to the difference between the cylinder  $ABLO$  and the conic frustum  $AQMB$ , all of the same common altitude  $IK$ .



## PROBLEMS.

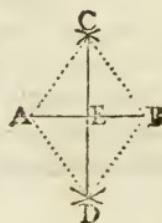
## PROBLEM I.

To Bisect a Line  $AB$ ; that is, to divide it into two Equal Parts.

From the two centres  $A$  and  $B$ , with any equal radii, describe arcs of circles, intersecting each other in  $C$  and  $D$ ; and draw the line  $CD$ , which will bisect the given line  $AB$  in the point  $E$ .

For, draw the radii  $AC$ ,  $BC$ ,  $AD$ ,  $BD$ . Then, because all these four radii are equal, and the side  $CD$  common, the two triangles  $ACD$ ,  $BCD$ , are mutually equilateral: consequently they are also mutually equiangular (th. 5), and have the angle  $ACE$  equal to the angle  $BCE$ .

Hence, the two triangles  $ACE$ ,  $BCE$ , having the two sides  $AC$ ,  $CE$ , equal to the two sides  $BC$ ,  $CE$ , and their contained angles equal, are identical (th. 1), and therefore have the side  $AE$  equal to  $EB$ . Q. E. D.

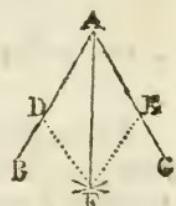


## PROBLEM II.

To Bisect an Angle  $BAC$ .

From the centre  $A$ , with any radius, describe an arc, cutting off the equal lines  $AD$ ,  $AE$ ; and from the two centres  $D$ ,  $E$ , with the same radius, describe arcs intersecting in  $F$ ; then draw  $AF$ , which will bisect the angle  $A$  as required.

For, join  $DF$ ,  $EF$ . Then the two triangles  $ADF$ ,  $AEF$ , having the two sides  $AD$ ,  $DF$ , equal to the two  $AE$ ,  $EF$  (being equal radii), and the side  $AF$  common, are mutually equilateral; consequently they are also mutually equiangular (th. 5), and have the angle  $BAF$  equal to the angle  $CAF$ .



*Scholium.* In the same manner is a given arc of a circle bisected.

## PROBLEM III.

**A**t a Given Point  $c$ , in a Line  $AB$ , to Erect a Perpendicular.

FRoM the given point  $c$ , with any radius, cut off any equal parts  $CD$ ,  $CE$ , of the given line; and, from the two centres  $D$  and  $E$ , with any one radius, describe arcs intersecting in  $F$ ; then join  $CF$ , which will be perpendicular as required.

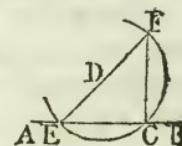


For, draw the two equal radii  $DF$ ,  $EF$ . Then the two triangles  $CDF$ ,  $CEF$ , having the two sides  $CD$ ,  $DF$ , equal to the two  $CE$ ,  $EF$ , and  $CF$  common, are mutually equilateral; consequently they are also mutually equiangular (th. 5), and have the two adjacent angles at  $C$  equal to each other; therefore the line  $CF$  is perpendicular to  $AB$  (def. 11).

*Otherwise.*

When the Given Point  $c$  is near the End of the Line.

FRoM any point  $D$ , assumed above the line, as a centre, through the given point  $c$  describe a circle, cutting the given line at  $E$ ; and through  $E$  and the centre  $D$ , draw the diameter  $EDF$ ; then join  $CF$ , which will be the perpendicular required.

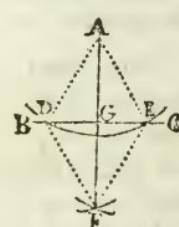


For the angle at  $c$ , being an angle in a semicircle, is a right angle, and therefore the line  $CF$  is a perpendicular (by def. 15).

## PROBLEM IV.

**F**rom a Given Point  $A$ , to let fall a Perpendicular on Line  $BC$ .

FRoM the given point  $A$  as a centre, with any convenient radius, describe an arc, cutting the given line at the two points  $D$  and  $E$ ; and from the two centres  $D$ ,  $E$ , with any radius, describe two arcs, intersecting at  $F$ ; then draw  $AF$ , which will be perpendicular to  $BC$  as required.



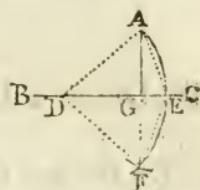
For, draw the equal radii  $AD$ ,  $AE$ , and  $AF$ . Then the two triangles  $ADF$ ,  $AEF$ , having the two sides  $AD$ ,  $DF$ , equal to the two  $AE$ ,  $EF$ , and  $AF$  common, are mutually

mutually equilateral; consequently they are also mutually equiangular (th. 5), and have the angle  $DAG$  equal the angle  $EAG$ . Hence then, the two triangles  $ADG$ ,  $AEG$ , having the two sides  $AD$ ,  $AG$ , equal to the two  $AE$ ,  $AG$ , and their included angles equal, are therefore equiangular (th. 1), and have the angles at  $G$  equal; consequently  $AG$  is perpendicular to  $BC$  (def. 11).

*Otherwise.*

When the Given Point is nearly Opposite the end of the Line.

FROM any point  $D$ , in the given line  $BC$ , as a centre, describe the arc of a circle through the given point  $A$ , cutting  $BC$  in  $E$ ; and from the centre  $E$ , with the radius  $EA$ , describe another arc, cutting the former in  $F$ ; then draw  $AGF$ , which will be perpendicular to be  $BC$  as required.

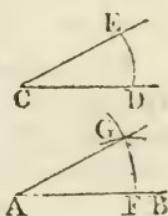


For, draw the equal radii  $DA$ ,  $DF$ , and  $EA$ ,  $EF$ . Then the two triangles  $DAE$ ,  $DFE$ , will be mutually equilateral; consequently they are also mutually equiangular (th. 5), and have the angles at  $D$  equal. Hence, the two triangles  $DAG$ ,  $DFG$ , having the two sides  $DA$ ,  $DG$ , equal to the two  $DF$ ,  $DG$ , and the included angles at  $D$  equal, have also the angles at  $G$  equal (th. 1); consequently those angles at  $G$  are right angles, and the line  $AG$  is perpendicular to  $DG$ .

#### PROBLEM V.

At a Given Point  $A$ , in a Line  $AB$ , to make an Angle Equal to a Given Angle  $c$ .

FROM the centres  $A$  and  $c$ , with any one radius, describe the arcs  $DE$ ,  $FG$ . Then, with centre  $F$ , and radius  $DE$ , describe an arc cutting  $FG$  in  $G$ . Through  $G$  draw the line  $AG$ , and it will form the angle required.

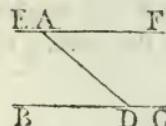


For, conceive the equal lines or radii,  $DE$ ,  $FG$ , to be drawn. Then the two triangles  $CDE$ ,  $AFG$ , being mutually equilateral, are mutually equiangular (th. 5), and have the angle at  $A$  equal to the angle  $c$ .

## PROBLEM VI.

Through a Given Point A, to draw a Line Parallel to a Given Line BC.

FROM the given point A draw the line AD to any point in the given line BC. Then draw the line EA<sub>F</sub> making the angle at A equal to the angle at D (by prob. 5); so shall EF be parallel to BC as required.

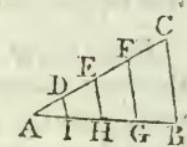


For, the angle D being equal to the alternate angle A, the lines BC, EF, are parallel, by th. 13.

## PROBLEM VII.

To Divide a Line AB into any proposed Number of Equal Parts.

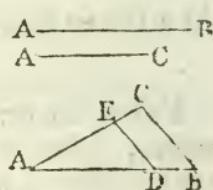
DRAW any other line AC, forming any angle with the given line AB; on which set off as many of any equal parts, AD, DE, EF, FC, as the line AB is to be divided into. Join BC; parallel to which draw the other lines FG, EH, DI: then these will divide AB in the manner as required.—For those parallel lines divide both the sides AB, AC, proportionally, by th. 82.



## PROBLEM VIII.

To find a Third Proportional to Two Lines AB, AC.

PLACE the two given lines AB, AC, forming any angle at A; and in AB take also AD equal to AC. Join BC, and draw DE parallel to it; so will AE be the third proportional sought.



For, because of the parallels BC, DE, the two lines AB, AC, are cut proportionally (th. 82); so that  $AB : AC :: AD : AE$ ; therefore AE is the third proportional to AB, AC.

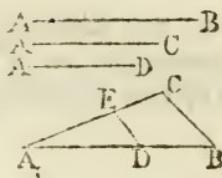
## PROBLEM IX.

To find a Fourth Proportional to three Lines AB, AC, AD.

PLACE two of the given lines AB, AC, making any angle at A; also place AD on AB. Join BC; and parallel to

¶ it draw  $DE$ : so shall  $AE$  be the fourth proportional as required.

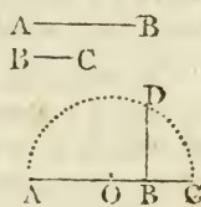
For, because of the parallels  $BC$ ,  $DE$ , the two sides  $AB$ ,  $AC$ , are cut proportionally (th. 82); so that - - - - -  
 $AB : AC :: AD : AE$ .



## PROBLEM X.

To find a Mean Proportional between Two Lines  $AB$ ,  $BC$ .

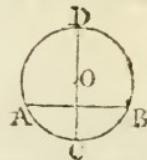
PLACE  $AB$ ,  $BC$ , joined in one straight line  $AC$ , which biseect in the point  $O$ . Then, with the centre  $O$ , and radius  $OA$  or  $OC$ , describe the semicircle  $ADC$ ; to meet which erect the perpendicular  $BD$ , and it will be the mean proportional sought, between  $AB$  and  $BC$  (by cor. th. 87).



## PROBLEM XI.

To find the Centre of a Circle.

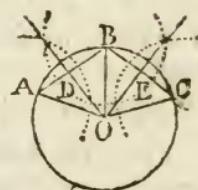
DRAW any chord  $AB$ ; and biseect it perpendicularly with the line  $CD$ , which will be a diameter (th. 41, cor.). Therefore  $GD$  biseected in  $O$ , will give the centre, as required.



## PROBLEM XII.

To describe the Circumference of a Circle through Three Points  $A$ ,  $B$ ,  $C$ .

FROM the middle point  $B$  draw chords  $BA$ ,  $BC$ , to the two other points, and biseect these chords perpendicularly by lines meeting in  $O$ , which will be the centre. Then from the centre  $O$ , at the distance of any one of the points, as  $OA$ , describe a circle, and it will pass through the two other points  $B$ ,  $C$ , as required.



For, the two right-angled triangles  $OAD$ ,  $OBG$ , having the sides  $AD$ ,  $DB$ , equal (by constr.), and  $OD$  common, with the included right angles at  $D$  equal, have their third sides

$oA$ ,  $oB$ , also equal (th. 1). And, in like manner, it is shewn that  $oC$  is equal to  $oB$  or  $oA$ . So that all the three  $oA$ ,  $oB$ ,  $oC$ , being equal, will be radii of the same circle.

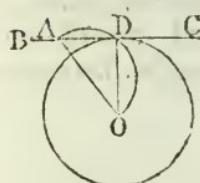
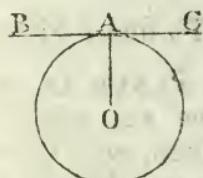
## PROBLEM XIII.

To draw a Tangent to a Circle, through a Given Point A.

WHEN the given point A is in the circumference of the circle: Join A and the centre o; perpendicular to which draw  $BAC$ , and it will be the tangent, by th. 46.

But when the given point A is out of the circle: Draw  $AO$  to the centre o; on which as a diameter describe a semicircle, cutting the given circumference in D; through which draw  $BADC$ , which will be the tangent as required.

For, join  $DO$ . Then the angle  $ADO$ , in a semicircle, is a right angle, and consequently  $AD$  is perpendicular to the radius  $DO$ , or is a tangent to the circle (th. 46).

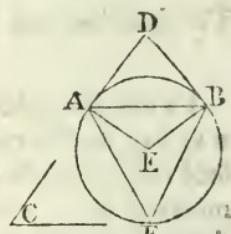


## PROBLEM XIV.

On a Given Line AB to describe a Segment of a Circle, that may Contain a Given Angle c.

AT the ends of the given line make angles  $DAB$ ,  $DBA$ , each equal to the given angle c. Then draw  $AE$ ,  $BE$ , perpendicular to  $AD$ ,  $BD$ ; and with the centre E, and radius  $EA$  or  $EB$ , describe a circle, so shall  $AFB$  be the segment required, as any angle F made in it will be equal to the given angle c.

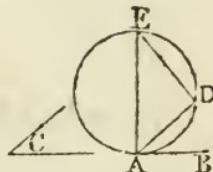
For, the two lines  $AD$ ,  $BD$ , being perpendicular to the radii  $EA$ ,  $EB$  (by constr.), are tangents to the circle (th. 46); and the angle A or B, which is equal to the given angle c by construction, is equal to the angle F in the alternate segment  $AFB$  (th. 53).



## PROBLEM XV.

To Cut off a Segment from a Circle, that shall Contain a Given Angle c.

DRAW any tangent AB to the given circle; and a chord AD to make the angle DAB equal to the given angle c; then DEA will be the segment required, any angle E made in it being equal to the given angle c.



For the angle A, made by the tangent and chord, which is equal to the given angle c by construction, is also equal to any angle E in the alternate segment (th. 53).

## PROBLEM XVI.

To make an Equilateral Triangle on a Given Line AB.

FROM the centres A and B, with the distance AB, describe arcs, intersecting in C. Draw AC, BC, and ABC will be the equilateral triangle.

For the equal radii AC, BC, are, each of them, equal to AB.

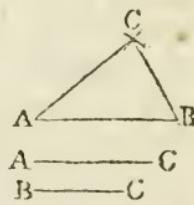


## PROBLEM XVII.

To make a Triangle with Three Given Lines AB, AC, BC.

WITH the centre A, and distance AC, describe an arc. With the centre B, and distance BC, describe another arc, cutting the former in C. Draw AC, BC, and ABC will be the triangle required.

For the radii, or sides of the triangle, AC, BC, are equal to the given lines AC, BC, by construction.

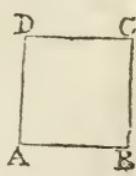


## PROBLEM XVIII.

To make a Square on a Given Line AB.

RAISE AD, BC, each perpendicular and equal to AB; and join DC; so shall ABCD be the square sought.

For all the three sides AB, AD, BC, are equal, by the construction, and DC is equal and parallel to AB (by th. 24); so that all the four



four sides are equal, and the opposite ones are parallel. Again, the angle A or B, of the parallelogram, being a right angle, the angles are all right ones (cor. 1, th. 22). Hence, then, the figure, having all its sides equal, and all its angles right, is a square (def. 34).

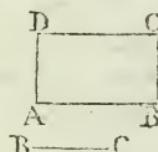
## PROBLEM XIX.

To make a Rectangle, or a Parallelogram, of a Given Length and Breadth, AB, BC.

ERECT AD, BC, perpendicular to AB, and each equal to BC; then join DC, and it is done.

The demonstration is the same as the last problem.

And in the same manner is described any oblique parallelogram, only drawing AD and BC to make the given oblique angle with AB, instead of perpendicular to it.



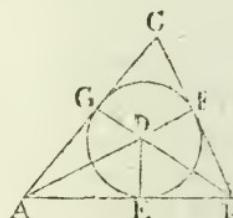
## PROBLEM XX.

To Inscribe a Circle in a Given Triangle ABC.

BISECT the angles at A and B, with the two lines AD, BD. From the intersection D, which will be the centre of the circle, draw the perpendiculars DE, DF, DG, and they will be the radii of the circle required.

For, since the angle DAE is equal to the angle DAG, and the angles at E, G, right angles (by constr.), the two triangles ADE, ADG, are equiangular; and, having also the side AD common, they are identical, and have the sides DE, DG, equal (th. 2). In like manner it is shewn, that DF is equal to DE or DG.

Therefore, if with the centre D, and distance DE, a circle be described, it will pass through all the three points E, F, G, in which points also it will touch the three sides of the triangle (th. 46), because the radii DE, DF, DG, are perpendicular to them.



## PROBLEM XXI.

To Describe a Circle about a Given Triangle ABC.

BISECT any two sides with two of the perpendiculars DE, DF, DG, and D will be the centre.

For, join DA, DB, DC. Then the two right-angled triangles DAE, DBE, have the two sides DE, EA, equal to the two DE, EB, and the included angles at E equal: those two triangles are therefore identical (th. 1), and have the side DA equal to DB. In like manner it is shewn, that DC is also equal to DA or DB. So that all the three DA, DB, DC, being equal, they are radii of a circle passing through A, B, and C.

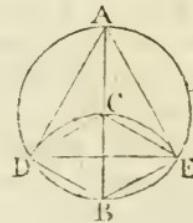


## PROBLEM XXII.

To Inscribe an Equilateral Triangle in a Given Circle.

THROUGH the centre c draw any diameter AB. From the point B as a centre, with the radius BC of the given circle, describe an arc DCE. Join AD, AE, DE, and ADE is the equilateral triangle sought.

For, join DB, DC, EB, EC. Then DCB is an equilateral triangle, having each side equal to the radius of the given circle. In like manner, BCE is an equilateral triangle. But the angle ADE is equal to the angle ABE or CBE, standing on the same arc AE; also the angle AED is equal to the angle CBD, on the same arc AD; hence the triangle DAE has two of its angles, ADE, AED, equal to the angles of an equilateral triangle, and therefore the third angle at A is also equal to the same; so that triangle is equiangular, and therefore equilateral.



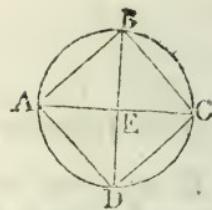
## PROBLEM XXIII.

To Inscribe a Square in a Given Circle.

DRAW two diameters AC, BD, crossing at right angles in the centre E. Then join the four extremities A, B, C, D, with

with right lines, and these will form the inscribed square ABCD.

For the four right-angled triangles AEB, BEC, CED, DEA, are identical, because they have the fides EA, EB, EC, ED, all equal, being radii of the circle, and the four included angles at E all equal, being right angles, by the construction. Therefore all their third sides AB, BC, CD, DA, are equal to one another, and the figure ABCD is equilateral. Also, all its four angles A, B, C, D, are right ones, being angles in a semicircle. Consequently the figure is a square.

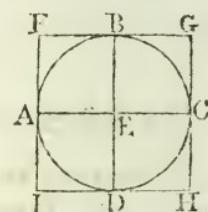


## PROBLEM XXIV.

To Describe a Square about a Given Circle.

DRAW two diameters AC, BD, crossing at right angles in the centre E. Then through the four extremities of them draw FG, IH, parallel to AC, and FI, GH, parallel to BD, and they will form the square FGHI.

For, the opposite sides of parallelograms being equal, FG and IH are each equal to the diameter AC, and FI and GH each equal to the diameter BD; so that the figure is equilateral. Again, because the opposite angles of parallelograms are equal, all the four angles F, G, H, I, are right angles, being equal to the opposite angles at E. So that the figure FGHI, having its sides equal, and its angles right ones, is a square, and its sides touch the circle at the four points A, B, C, D, being perpendicular to the radii drawn to those points.



## PROBLEM XXV.

To Inscribe a Circle in a Given Square.

BISECT the two fides FG, FI, in the points A and B (last fig.). Then through these two points draw AC parallel to FG or IH, and BD parallel to FI or GH. Then the point of intersection E will be the centre, and the four lines EA, EB, EC, ED, radii of the inscribed circle.

For, because the four parallelograms EF, EG, EH, EI, have their opposite sides and angles equal, therefore all the four lines

lines  $EA$ ,  $EB$ ,  $EC$ ,  $ED$ , are equal, being each equal to half a side of the square. So that a circle described from the centre  $E$ , with the distance  $EA$ , will pass through all the points  $A$ ,  $B$ ,  $C$ ,  $D$ , and will be inscribed in the square, or will touch its four sides in those points, because the angles there are right ones.

## PROBLEM XXVI.

To Describe a Circle about a Given Square,  
(see fig. Prob. xxiii.).

DRAW the diagonals  $AC$ ,  $BD$ , and their intersection  $E$  will be the centre.

For the diagonals of a square bisect each other (th. 40), making  $EA$ ,  $EB$ ,  $EC$ ,  $ED$ , all equal, and consequently these are radii of a circle passing through the four points  $A$ ,  $B$ ,  $C$ ,  $D$ .

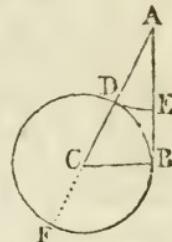
## PROBLEM XXVII.

To Cut a Given Line in Extreme and Mean Ratio.

LET  $AB$  be the given line to be divided in extreme and mean ratio, that is, so as that the whole line may be to the greater part, as the greater part is to the less part.

Draw  $BC$  perpendicular to  $AB$ , and equal to half  $AB$ . Join  $AC$ ; and with centre  $C$  and distance  $CB$ , describe the circle  $BD$ ; then with centre  $A$  and distance  $AD$ , describe the arc  $DE$ ; so shall  $AB$  be divided in  $E$  in extreme and mean ratio, or so that  $AB : AE :: AE : EB$ .

For, produce  $AC$  to the circumference at  $F$ . Then,  $ADF$  being a secant, and  $AB$  a tangent, because  $B$  is a right angle: therefore the rectangle  $AF \cdot AD$  is equal to  $AB^2$  (cor. 1, th. 61); consequently the means and extremes of these are proportional (th. 77), or  $AB : AF$  or  $AD + DF :: AD : AB$ . But  $AE$  is equal to  $AD$  by construction, and  $AB = 2BC = DF$ ; therefore,  $AB : AE + AB :: AE : AB$ ; and by division,  $AB : AE :: AE : EB$ .



## PROBLEM XXVIII.

To Inscribe an Isosceles Triangle in a Given Circle, that shall have each of the Angles at the Base Double the Angle at the Vertex.

DRAW any diameter  $AB$  of the given circle; and divide the radius  $CB$ , in the point  $D$ , in extreme and mean ratio, by the last problem. From the point  $B$  apply the chords  $BE$ ,  $BF$ , each equal to the greater part  $CD$ . Then join  $AE$ ,  $AF$ ,  $EF$ ; and  $AEF$  will be the triangle required.

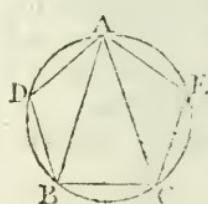
For, the chords  $BE$ ,  $BF$ , being equal, their arcs are equal; therefore the supplemental arcs and chords  $AE$ ,  $AF$ , are also equal; consequently the triangle  $AEF$  is isosceles, and has the angle  $E$  equal to the angle  $F$ ; also the angles at  $G$  are right angles.

Draw  $CF$  and  $DF$ . Then,  $BC : CD :: CD : BD$ , or  $BC : BF :: BF : BD$  by constr. And  $BA : BF :: BF : BG$  (by th. 87). But  $BC = \frac{1}{2}BA$ ; therefore  $BG = \frac{1}{2}BD = GD$ ; therefore the two triangles  $GBF$ ,  $GDF$ , are identical (th. 1), and each equiangular to  $ABF$  and  $AGF$  (th. 87). Therefore their doubles,  $BFD$ ,  $AFE$ , are isosceles and equiangular, as well as the triangle  $BCF$ ; having the two sides  $BC$ ,  $CF$ , equal, and the angle  $B$  common with the triangle  $BFD$ . But  $CD$  is  $= DF$  or  $BF$ ; therefore the angle  $C =$  the angle  $DFC$  (th. 4); consequently the angle  $BDF$ , which is equal to the sum of these two equal angles (th. 16), is double of one of them  $C$ ; or the equal angle  $B$  or  $CFB$  double the angle  $C$ . So that  $CBF$  is an isosceles triangle, having each of its two equal angles double of the third angle  $C$ . Consequently the triangle  $AEF$  (which it has been shewn is equiangular to the triangle  $CBF$ ) has also each of its angles at the base double the angle  $A$  at the vertex.

## PROBLEM XXIX.

To Inscribe a Regular Pentagon in a Given Circle.

INSCRIBE the isosceles triangle  $ABC$  having each of the angles  $ABC$ ,  $ACB$ , double the angle  $BAC$  (prob. 28). Then bisect the two arcs  $ADB$ ,  $AEC$ , in the points  $D$ ,  $E$ ; and draw the chords  $AD$ ,  $DB$ ,  $AE$ ,  $EC$ , so shall  $ADBCE$  be the inscribed equilateral pentagon required.



For,

For, because equal angles stand on equal arcs, and double angles on double arcs, also the angles  $ABC$ ,  $ACB$ , being each double the angle  $BAC$ , therefore the arcs  $ADB$ ,  $AEC$ , subtending the two former angles, are each double the arc  $BC$  subtending the latter. And since the two former arcs are bisected in  $D$  and  $E$ , it follows that all the five arcs  $AD$ ,  $DB$ ,  $BC$ ,  $CE$ ,  $EA$ , are equal to each other, and consequently the chords also which subtend them, or the five sides of the pentagon, are all equal.

*Note.* In the construction, the points  $D$  and  $E$  are most easily found, by applying  $BD$  and  $CE$  each equal to  $BC$ .

## PROBLEM XXX.

To Inscribe a Regular Hexagon in a Circle.

APPLY the radius of the given circle  $AO$ , as a chord, quite round the circumference, and it will make the regular hexagon  $ABCDEF$ .

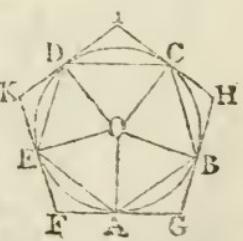
For, draw the radii  $AO$ ,  $BO$ ,  $CO$ ,  $DO$ ,  $EO$ ,  $FO$ . Then the triangle  $ABO$  being equilateral (by constr.), its three angles are all equal (cor. 2, th. 3), and any one of them, as  $AOB$ , is one-third of two right angles (th. 17), or one-sixth of four right angles. But the whole circumference is the measure of four right angles (cor. 4, th. 6). Therefore the arc  $AB$  is one-sixth of the circumference of the circle, and consequently its chord  $AB$  one side of an equilateral hexagon inscribed in the circle. And the same of the other chords.

*Corol.* The side of a regular hexagon is equal to the radius of the circumscribing circle, or to the chord of one-sixth part of the circumference.

## PROBLEM XXXI.

To Describe a Regular Pentagon or Hexagon about a Circle.

IN the given circle inscribe a regular polygon of the same name or number of sides, as  $ABCDE$ , by one of the foregoing problems. Then to all the angular points of it draw tangents (by prob. 13), and these will form the circumscribing polygon required.



For,

For, all the chords, or sides of the inscribing figure,  $AB$ ,  $BC$ , &c, being equal, and all the radii  $OA$ ,  $OB$ , &c, being equal, all the vertical angles about the point  $O$  are equal. But the angles  $OEF$ ,  $OAF$ ,  $OAG$ ,  $OBG$ , made by the tangents and radii, are right angles; therefore  $OEF + OAF =$  two right angles, and  $OAG + OBG =$  two right angles; consequently, also,  $AOE + AFE =$  two right angles, and  $AOB + AGB =$  two right angles (cor. 2, th. 18). Hence, then, the angles  $AOE + AFE$  being  $= AOB + AGB$ , of which  $AOB$  is  $= AOE$ ; consequently the remaining angles  $F$  and  $G$  are also equal. In the same manner it is shewn, that all the angles  $F$ ,  $G$ ,  $H$ ,  $I$ ,  $K$ , are equal.

Again, the tangents from the same point  $FE$ ,  $FA$ , are equal, as also the tangents  $AG$ ,  $GB$  (th. 61, cor. 2); and the angles  $F$  and  $G$  of the isosceles triangles  $AFE$ ,  $AGB$ , are equal, as well as their opposite sides  $AE$ ,  $AB$ ; consequently those two triangles are identical (th. 1), and have their other sides  $EF$ ,  $FA$ ,  $AG$ ,  $GB$ , all equal, and  $FG$  equal to the double of any one of them. In like manner it is shewn that all the other sides  $GH$ ,  $HI$ ,  $IK$ ,  $KF$ , are equal to  $FG$ , or double of the tangents  $GB$ ,  $BH$ , &c.

Hence, then, the circumscribed figure is both equilateral and equiangular, which was to be shewn.

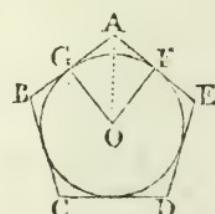
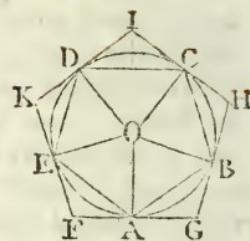
*Corol.* The inscribed circle touches the middles of the sides of the polygon.

### PROBLEM XXXII.

To Inscribe a Circle in a Regular Polygon.

**BISECT** any two sides of the polygon by the perpendiculars  $GO$ ,  $FO$ , and their intersection  $O$  will be the centre of the inscribed circle, and  $OG$  or  $OF$  will be the radius.

For the perpendiculars to the tangents  $AF$ ,  $AG$ , pass through the centre (cor. th. 47); and the inscribed circle touches the middle points  $F$ ,  $G$ , by the last corollary. Also, the two sides  $AG$ ,  $AO$ , of the right-angled triangle  $AOG$ , being equal to the two sides  $AF$ ,  $AO$ , of the right-angled triangle  $AOF$ , the third sides  $OF$ ,  $OG$ , will also be equal (cor. th. 45). Therefore the



the circle described with the centre o and radius  $oG$ , will pass through F, and will touch the sides in the points G and F. And the same for all the other sides of the figure.

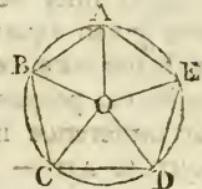
## PROBLEM XXXIII.

To Describe a Circle about a Regular Polygon.

BISECT any two of the angles, C and D, with the lines CO, DO; then their intersection o will be the centre of the circumscribing circle; and OC, or OD, will be the radius.

For, draw OB, OA, OE, &c, to the angular points of the given polygon.

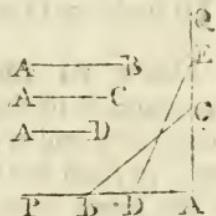
Then the triangle OCD is isosceles, having the angles at C and D equal, being the halves of the equal angles of the polygon BCD, CDE; therefore their opposite sides CO, DO, are equal (th. 4). But the two triangles OCD, OCB, having the two sides OC, CD, equal to the two OC, CB, and the included angles OCD, OCB, also equal, will be identical (th. 1), and have their third sides EO, OD, equal. In like manner it is shewn, that all the lines OA, OB, OC, OD, OE, are equal. Consequently a circle described with the centre o and radius OA, will pass through all the other angular points, B, C, D, &c, and will circumscribe the polygon.



## PROBLEM XXXIV.

To make a Square Equal to the Sum of two Given Squares.

LET AB and AC be the sides of the two given squares. Draw two indefinite lines AP, AQ, at right angles to each other; in which place the sides AB, AC, of the given squares; join BC; then a square described on BC will be equal to the sum of the two squares described on AB and AC (th. 34).



*Scholium.* In the same manner, a square may be made equal to the sum of three or more given squares. For, if AB, AC, AD, be taken as the sides of the given squares, then, making AE = BC, AD = AD, and drawing DE, it is evident that the square on DE will be equal to the sum of the three squares on AB, AC, AD. And so on for more squares.

## PROBLEM XXXV.

To make a Square Equal to the Difference of two Given Squares.

LET  $AB$  and  $AC$ , taken in the same straight line, be equal to the sides of the two given squares.—From the centre  $A$ , with the distance  $AB$ , describe a circle; and make  $CD$  perpendicular to  $AB$ , meeting the circumference in  $D$ : so shall a square described on  $CD$  be equal to  $AD^2 - AC^2$ , or  $AB^2 - AC^2$ , as required (cor. th. 34).

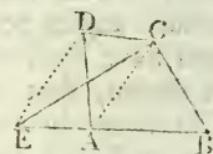


## PROBLEM XXXVI.

To make a Triangle Equal to a Given Quadrilateral ABCD.

DRAW the diagonal  $AC$ , and parallel to it  $DE$ , meeting  $BA$  produced at  $E$ , and join  $CE$ : then will the triangle  $CEB$  be equal to the given quadrilateral  $ABCD$ .

For, the two triangles  $ACE$ ,  $ACD$ , being on the same base  $AC$ , and between the same parallels  $AC$ ,  $DE$ , are equal (th. 25); therefore, if  $ABC$  be added to each, it will make  $BCE$  equal to  $ABCD$  (ax. 2).

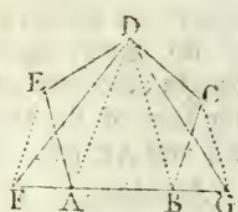


## PROBLEM XXXVII.

To make a Triangle Equal to a Given Pentagon ABCDE.

DRAW  $DA$  and  $DB$ , and also  $EF$ ,  $CG$ , parallel to them, meeting  $AB$  produced at  $F$  and  $G$ ; then draw  $DF$  and  $DG$ ; so shall the triangle  $DFG$  be equal to the given pentagon  $ABCDE$ .

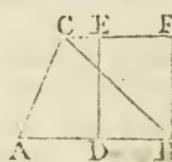
For the triangle  $DFA = DAE$ , and the triangle  $DGB = DCB$  (th. 25); therefore, by adding  $DAB$  to the equals, the sums are equal (ax. 2), that is,  $DAB + DAF + DEG = DAB + DAE + DBC$ , or the triangle  $DFG =$  to the pentagon  $AECDE$ .



## PROBLEM XXXVIII.

To make a Rectangle Equal to a Given Triangle ABC.

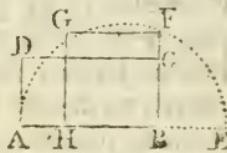
BISECT the base AB in D; then raise DE and BF perpendicular to AB, and meeting CF, parallel to AB, at E and F: so shall DF be the rectangle equal to the given triangle ABC (by cor. 2, th. 26).



## PROBLEM XXXIX.

To make a Square Equal to a Given Rectangle ABCD.

PRODUCE one side AB, till BE be equal to the other side BC. On AE as a diameter describe a circle, meeting BE produced at F: then will BF be the side of the square BFGH, equal to the given rectangle BD, as required, as appears by cor. th. 87, and th. 77.



## APPLICATION OF ALGEBRA

TO

## GEOMETRY.

**W**HEN it is proposed to resolve a geometrical problem algebraically, or by algebra, it is proper, in the first place, to draw a figure that shall represent the several parts or conditions of the problem, and to suppose that figure to be the true one. Then, having considered attentively the nature of the problem, the figure is next to be prepared for a solution, if necessary, by producing or drawing such lines in it as appear most conducive to that end. This done, the usual symbols or letters, for known and unknown quantities, are employed to denote the given parts of the figure, or as many of them as necessary, as also such unknown line or lines as may be easiest found, whether required or not. Then proceed to the operation, by observing the relations that the several parts of the figure have to each other; from which, and the proper theorems in the foregoing elements of geometry, make out as many equations independent of each other, as there are unknown quantities employed in them: the resolution of which equations, in the same manner as in arithmetical problems, will determine the unknown quantities, and resolve the problem proposed.

As no general rule can be given for drawing the lines, and selecting the fittest quantities to substitute for, so as always to bring out the most simple conclusions, because different problems require different modes of solution; the best way to gain experience in this matter, is to try the solution of the same problem in different ways, and then apply that which succeeds best, to other cases of the same kind, when they afterwards occur. The following particular directions, however, may be of some use in this matter.

1*a*, In preparing the figure, by drawing lines, let them be either parallel or perpendicular to other lines in the figure, or so as to form similar triangles. And if an angle be given, it will be proper to let the perpendicular be opposite to that angle, and to fall from one end of a given line, if possible.

2d, In selecting the quantities proper to substitute for, those are to be chosen, whether required or not, which lie nearest the known or given parts of the figure, and by means of which the next adjacent parts may be expressed by addition and subtraction only, without the intervention of surds.

3d, When two lines or quantities are alike related to other parts of the figure or problem, the best way is, not to make use of either of them separately, but to substitute for their sum, or difference, or rectangle, or the sum of their alternate quotients, or for some line or lines, in the figure, to which they have both the same relation.

4th, When the area, or the perimeter, of a figure, is given, or such parts of it as have only a remote relation to the parts required; it is sometimes of use to assume another figure similar to the proposed one, having one side equal to unity, or some other known quantity. For, from hence the other parts of the figure may be found, by the known proportions of the like sides, or parts, and so an equation be obtained.

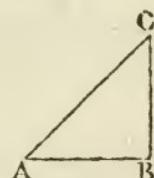
For examples of this matter take the following problems.

#### PROBLEM I.

*In a Right-angled Triangle, having given the Base (3), and the Sum of the Hypotenuse and Perpendicular (9); to find both these two Sides.*

LET ABC represent the proposed triangle, right-angled at B. Put the base AB = 3 =  $b$ , and the sum AC + BC of the hypotenuse and perpendicular = 9 =  $s$ ; also, let  $x$  denote the perpendicular BC; hence it follows that the hypotenuse AC will be expressed by  $s - x$ .

But  $AC^2 = AB^2 + BC^2$  (by theor. 34, Geom.); that is,  $(s - x)^2 = b^2 + x^2$ , or  $s^2 - 2sx + x^2 = b^2 + x^2$ , or  $s^2 - b^2 = 2sx$ ; hence  $x = \frac{s^2 - b^2}{2s} = 4 = BC$ , and  $s - x - \frac{s^2 + b^2}{2s} = 5 = AC$ , the perpendicular and hypotenuse as required.



## PROBLEM II.

In a Right-angled Triangle, having given the Hypotenuse (5); and the Sum of the Base and Perpendicular (7); to find both these two Sides.

LET ABC represent the proposed triangle, right-angled at B. Put the given hypotenuse AC = 5 =  $a$ , and the sum AB + BC of the base and perpendicular = 7 =  $s$ ; also, let  $x$  denote the base AB; hence it follows that the perpendicular BC will be expressed by  $s - x$ .

But  $AC^2 = AB^2 + BC^2$  by the nature of right-angled triangles; that is,  $a^2 = x^2 + (s - x)^2 = x^2 + s^2 - 2sx + x^2$ , or  $2x^2 - 2sx = a^2 - s^2$ , or  $x^2 - sx = \frac{1}{2}a^2 - \frac{1}{2}s^2$ ; hence, by completing the square, &c, is found  $x = \frac{1}{2}s - \frac{1}{2}\sqrt{2a^2 - s^2} = 3 = AB$ ; and  $s - x = \frac{1}{2}s + \frac{1}{2}\sqrt{2a^2 - s^2} = 4 = BC$ ; the base and perpendicular required.

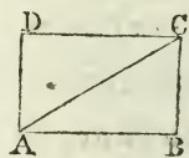
Otherwise.

LET  $z$  denote the difference of the base and perpendicular, the sum being denoted by  $s$ , as above. Then, because that, in any two quantities, half their difference added to half the sum gives the greater quantity, and the same subtracted gives the less quantity (by Ex. 2, Alg. pag. 239), it follows that  $\frac{1}{2}s + \frac{1}{2}z$  and  $\frac{1}{2}s - \frac{1}{2}z$  will denote the two legs, or the perpendicular and base. Hence then  $a^2 = (\frac{1}{2}s + \frac{1}{2}z)^2 + (\frac{1}{2}s - \frac{1}{2}z)^2 = \frac{1}{2}s^2 + \frac{1}{2}z^2$ ; or  $z^2 = 2a^2 - s^2$ , and  $z = \sqrt{2a^2 - s^2}$ . Then the half of this being added and subtracted with  $\frac{1}{2}s$ , the half sum, gives - - - - -  $\frac{1}{2}s + \frac{1}{2}z = \frac{1}{2}s + \frac{1}{2}\sqrt{2a^2 - s^2}$ , and  $\frac{1}{2}s - \frac{1}{2}z = \frac{1}{2}s - \frac{1}{2}\sqrt{2a^2 - s^2}$ , the same as before.

## PROBLEM III.

In a Rectangle, having given the Diagonal (10), and the Perimeter, or Sum of all the Four Sides (28); to find each of the Sides severally.

LET ABCD be the proposed rectangle; and put the diagonal AC = 10 =  $d$ , and half the perimeter AB + BC or AD + DC = 14 =  $a$ ; also put one side AB =  $x$ ; then the other side BC will be denoted by  $a - x$ . Hence, by right-angled triangles



$$AC^2$$

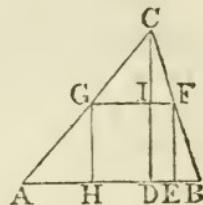
$AC^2 = AB^2 + BC^2$ , that is,  $d^2 = x^2 + (a - x)^2 = 2x^2 - 2ax + a^2$ : conseq.  $x^2 - ax = \frac{1}{2}d^2 - \frac{1}{2}a^2$ , and by completing the square, &c,  $x = \frac{1}{2}a + \frac{1}{2}\sqrt{2d^2 - a^2} = 8 = AB$ , and  $a - x = \frac{1}{2}a - \frac{1}{2}\sqrt{2d^2 - a^2} = 6 = BC$ , the two sides; and the same for the other two  $AD, DC$ .

Or, by substituting for the sum and difference of the two sides,  $AB, BC$ , this problem may be resolved, like the latter method of the foregoing one, by a simple quadratic, and consequently without completing the square.

## PROBLEM IV.

*Having given the Base and Perpendicular of any Triangle; to find the Side of a Square Inscribed in the same.*

LET  $ABC$  represent the given triangle, and  $EFGH$  its inscribed square. Put the base  $AB = b$ , the perpendicular  $CD = a$ , and the side of the square  $GF$  or  $GH = DI = x$ ; then will  $CI = CD - DI = a - x$ .

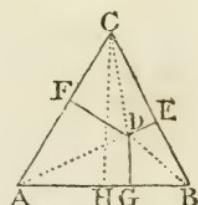


Then, because the like lines in the similar triangles  $ABC, GFC$ , are proportional, (by theor. 84, Geom.),  $AB : CD :: GF : CI$ , that is,  $b : a :: x : a - x$ . Hence  $ab - bx = ax$ , or  $ab = ax + bx$ , and consequently  $x = \frac{ab}{a+b} = GF$  or  $GH$  the side of the inscribed square; which therefore is of the same magnitude, whatever the species or the angles of the triangles may be.

## PROBLEM V.

*In an Equilateral Triangle, having given the lengths of the three Perpendiculars, drawn from a certain Point within, on the three Sides; to determine the Sides.*

LET  $ABC$  represent the equilateral triangle, and  $DE, DF, DG$ , the given perpendiculars from the point  $D$ . Draw the lines  $DA, DB, DC$ , to the three angular points; and let fall the perpendicular  $CH$  on the base  $AB$ . Put the three given perpendiculars  $DE = a$ ,  $DF = b$ ,  $DG = c$ , and put  $x = AH$  or  $BH$ , half the side of the equilateral triangle. Then is  $AC$  or  $BC = 2x$ , and by right-angled triangles the perpendicular  $CH = \sqrt{AC^2 - AH^2} = \sqrt{4x^2 - x^2} = \sqrt{3x^2} = x\sqrt{3}$ .



Now, since the area or space of a rectangle is expressed by the product of the base and height (cor. 2, th. 81, Geom.), and that a triangle is equal to half a rectangle of equal base and height (cor. 1, th. 26); it follows that,

the whole triangle  $ABC$  is  $= \frac{1}{2}AB \times CH = x \times x\sqrt{3} = x^2\sqrt{3}$ ,  
 the triangle  $ABD = \frac{1}{2}AB \times DG = x \times c = cx$ ,  
 the triangle  $BCD = \frac{1}{2}BC \times DE = x \times a = ax$ ,  
 the triangle  $ACD = \frac{1}{2}AC \times DF = x \times b = bx$ .

But the three last triangles make up, or are equal to, the whole former or great triangle;  
 that is,  $x^2\sqrt{3} = ax + bx + cx$ ; hence  
 then  $x\sqrt{3} = a + b + c$ , and  
 $x = \frac{a + b + c}{\sqrt{3}}$ , half the side of the triangle sought.

Also, since the whole perpendicular  $CH$  is  $= x\sqrt{3}$ , it is therefore  $= a + b + c$ . That is, the whole perpendicular  $CH$ , is just equal to the sum of all the three smaller perpendiculars  $DE + DF + DG$  taken together, wherever the point  $D$  is situated.

#### PROBLEM VI.

IN a Right-angled Triangle, having given the Base (3), and the Difference between the Hypotenuse and Perpendicular (1); to find both these two Sides.

#### PROBLEM VII.

IN a Right-angled Triangle, having given the Hypotenuse (5), and the Difference between the Base and Perpendicular (1); to determine both these two Sides.

#### PROBLEM VIII.

HAVING given the Area, or Measure of the Space, of a Rectangle, inscribed in a given Triangle; to determine the Sides of the Rectangle.

#### PROBLEM IX.

IN a Triangle, having given the Ratio of the two Sides, together with both the Segments of the Base, made by a Perpendicular from the Vertical Angle; to determine the Sides of the Triangle.

#### PROBLEM X.

IN a Triangle, having given the Base, the Sum of the other two Sides, and the Length of a Line drawn from the Vertical Angle to the Middle of the Base; to find the sides of the Triangle.

#### PROBLEM

## PROBLEM XI.

IN a Triangle, having given the two Sides, about the Vertical Angle, with the Line bisecting that Angle, and terminating in the Base; to find the Base.

## PROBLEM XII.

To determine the Radii of three Equal Circles, described in a given Circle, to touch each other and also the Circumference of the given Circle.

## PROBLEM XIII.

IN a Right-angled Triangle, having given the Perimeter or Sum of all the Sides, and the Perpendicular let fall from the Right Angle on the Hypotenuse; to determine the Triangle, that is, its Sides.

## PROBLEM XIV.

To determine a Right-angled Triangle; having given the Perimeter, and the Radius of its Inscribed Circle.

## PROBLEM XV.

To determine a Right-angled Triangle; having given the Lengths of two Lines drawn from the acute Angles, to the Middle of the opposite Sides.

## PROBLEM XVI.

To determine a Right-angled Triangle; having given the Hypotenuse, and the Difference of two Lines drawn from the two acute Angles to the Centre of the Inscribed Circle.

## PROBLEM XVII.

To determine a Triangle; having given the Base, the Perpendicular, and the Ratio of the two Sides.

## PROBLEM XVIII.

To determine a Right-angled Triangle; having given the Hypotenuse, and the Side of the Inscribed Square.

## PROBLEM XIX.

To determine a Triangle ; having given the Base, the Perpendicular, and the Difference of the two other Sides.

## PROBLEM XX.

To determine a Triangle ; having given the Base, the Perpendicular, and the Rectangle or Product of the two Sides.

## PROBLEM XXI.

To determine a Triangle ; having given the Lengths of three Lines drawn from the three Angles, to the Middle of the opposite Sides.

## PROBLEM XXII.

In a Triangle, having given all the three Sides ; to find the Radius of the Inscribed Circle.

## PROBLEM XXIII.

To determine a Right-angled Triangle ; having given the Side of the Inscribed Square, and the Radius of the Inscribed Circle.

## PROBLEM XXIV.

To determine a Triangle, and the Radius of the Inscribed Circle ; having given the Lengths of three Lines drawn from the three Angles, to the Centre of that Circle.

## PROBLEM XXV.

To determine a Right-angled Triangle ; having given the Hypotenuse, and the Radius of the Inscribed Circle.

## PROBLEM XXVI.

To determine a Triangle ; having given the Base, the Line bisecting the Vertical Angle, and the Diameter of the Circumscribing Circle.

# LOGARITHMS

OF THE

## NUMBERS

FROM

1 to 10000.

N.	Log.	N.	Log.	N.	Log.	N.	Log.
1	0.000000	26	1.414973	51	1.707576	76	1.880814
2	0.301030	27	1.431364	52	1.716003	77	1.886491
3	0.477121	28	1.447158	53	1.724276	78	1.892095
4	0.602060	29	1.462398	54	1.732394	79	1.897627
5	0.698970	30	1.477121	55	1.740363	80	1.903090
6	0.778151	31	1.491362	56	1.748188	81	1.908485
7	0.845098	32	1.505150	57	1.755875	82	1.913814
8	0.903090	33	1.518514	58	1.763428	83	1.919078
9	0.954243	34	1.531479	59	1.770852	84	1.924279
10	1.000000	35	1.544068	60	1.778151	85	1.929419
11	1.041393	36	1.556303	61	1.785330	86	1.934498
12	1.079181	37	1.568202	62	1.792392	87	1.939519
13	1.113943	38	1.579784	63	1.799341	88	1.944483
14	1.146128	39	1.591065	64	1.806180	89	1.949390
15	1.176091	40	1.602060	65	1.812913	90	1.954243
16	1.204120	41	1.612784	66	1.819544	91	1.959041
17	1.230449	42	1.623249	67	1.826075	92	1.963788
18	1.255273	43	1.633468	68	1.832509	93	1.968483
19	1.278754	44	1.643453	69	1.838849	94	1.973128
20	1.301030	45	1.653213	70	1.845098	95	1.977724
21	1.322219	46	1.662758	71	1.851258	96	1.982271
22	1.342423	47	1.672098	72	1.857333	97	1.986772
23	1.361728	48	1.681241	73	1.863323	98	1.991226
24	1.380211	49	1.690196	74	1.869232	99	1.995635
25	1.397940	50	1.698970	75	1.875061	100	2.000000

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103	012837	3259	3680	4100	4521	4940	5360	5779	6197	6616
104	7033	7451	7868	8284	8700	9116	9532	9947	0361	0775
105	021189	1603	2016	2428	2841	3252	3664	4075	4486	4896
106	5306	5715	6125	6533	6942	7350	7757	8164	8571	8978
107	9384	9789	0195	0600	1004	1408	1812	2216	2619	3021
108	033424	3826	4227	4628	5029	5430	5830	6230	6629	7028
109	7426	7825	8223	8620	9017	9414	9811	0207	0602	0998
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111	5323	5714	6105	6495	6885	7275	7664	8053	8442	8830
112	9218	9606	9993	0380	0766	1153	1538	1924	2309	2694
113	053078	3463	3846	4230	4613	4996	5378	5760	6142	6524
114	6905	7286	7666	8046	8426	8805	9185	9563	9942	0320
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118	071882	2250	2617	2985	3352	3718	4085	4451	4816	5182
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122	6360	6716	7071	7426	7781	8136	8490	8845	9198	9552
123	9905	0258	0611	0963	1315	1667	2018	2370	2721	3071
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125	6910	7257	7604	7951	8298	8644	8990	9335	9681	0026
126	100371	0715	1059	1403	1747	2091	2434	2777	3119	3462
127	3804	4146	4487	4828	5169	5510	5851	6191	6531	6871
128	7210	7549	7888	8227	8565	8903	9241	9579	9916	0253
129	110590	0926	1263	1599	1934	2270	2605	2940	3275	3609
130	3943	4277	4611	4944	5278	5611	5943	6276	6608	6940
131	7271	7603	7934	8265	8595	8926	9256	9586	9915	0245
132	120574	0903	1231	1560	1888	2216	2544	2871	3198	3525
133	3852	4178	4504	4830	5156	5481	5806	6131	6456	6781
134	7105	7429	7753	8076	8399	8722	9045	9368	9690	0012
135	130334	0655	0977	1298	1619	1939	2260	2580	2900	3219
136	3539	3858	4177	4496	4814	5133	5451	5769	6086	6403
137	6721	7037	7354	7671	7987	8303	8618	8934	9249	9564
138	9879	0194	0508	0822	1136	1450	1763	2076	2389	2702
139	143015	3327	3639	3951	4263	4574	4885	5196	5507	5818
140	6128	6438	6748	7058	7367	7676	7985	8294	8603	8911
141	9219	9527	9835	0142	0449	0756	1063	1370	1676	1982
142	152288	2594	2900	3205	3510	3815	4120	4424	4728	5032
143	5336	5640	5943	6246	6549	6852	7154	7457	7759	8061
144	8362	8664	8965	9266	9567	9868	0168	0469	0769	1068
145	161368	1667	1967	2266	2564	2863	3161	3460	3758	4055
146	4353	4650	4947	5244	5541	5838	6134	6430	6726	7022
147	7317	7613	7908	8203	8497	8792	9086	9380	9674	9968
148	170262	0555	0848	1141	1434	1726	2019	2311	2603	2895
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152	181844	2129	2415	2700	2985	3270	3555	3839	4123	4407
153	4691	4975	5259	5542	5825	6108	6391	6674	6956	7239
154	7521	7803	8084	8366	8647	8928	9209	9490	9771	0051
155	190332	0612	0892	1171	1451	1730	2010	2289	2567	2846
156	3125	3403	3681	3959	4237	4514	4792	5069	5346	5623
157	5899	6176	6453	6729	7005	7281	7556	7832	8107	8382
158	8657	8932	9206	9481	9755	0029	0303	0577	0850	1124
159	201397	1670	1943	2216	2488	2761	3033	3305	3577	3848
160	4120	4391	4663	4934	5204	5475	5746	6016	6286	6556
161	6826	7096	7365	7634	7904	8173	8441	8710	8979	9247
162	9515	9783	0051	0319	0586	0853	1121	1388	1654	1921
163	212188	2454	2720	2986	3252	3518	3783	4049	4314	4579
164	4844	5109	5373	5638	5902	6166	6430	6694	6957	7221
165	7484	7747	8010	8273	8536	8798	9060	9323	9585	9846
166	220108	0370	0631	0892	1153	1414	1675	1936	2196	2456
167	2716	2976	3236	3496	3755	4015	4274	4533	4792	5051
168	5309	5568	5826	6084	6342	6600	6858	7115	7372	7630
169	7887	8144	8400	8657	8913	9170	9426	9682	9938	0193
170	230449	0704	0960	1215	1470	1724	1979	2234	2488	2742
171	2996	3250	3504	3757	4011	4264	4517	4770	5023	5276
172	5528	5781	6033	6285	6537	6789	7041	7292	7544	7795
173	8046	8297	8548	8799	9049	9299	9550	9800	0050	0300
174	240549	0799	1048	1297	1546	1795	2044	2293	2541	2790
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176	5513	5759	6006	6252	6499	6745	6991	7237	7482	7728
177	7973	8219	8464	8709	8954	9198	9443	9687	9932	0176
178	250420	0664	0908	1151	1395	1638	1881	2125	2368	2610
179	2853	3096	3338	3580	3822	4064	4306	4548	4790	5031
180	5273	5514	5755	5996	6237	6477	6718	6958	7198	7439
181	7679	7918	8158	8398	8637	8877	9116	9355	9594	9833
182	260071	0310	0548	0787	1025	1263	1501	1739	1976	2214
183	2451	2688	2925	3162	3399	3636	3873	4109	4346	4582
184	4818	5054	5290	5525	5761	5996	6232	6467	6702	6937
185	7172	7406	7641	7875	8110	8344	8580	8812	9046	9279
186	9513	9746	9980	0213	0446	0679	0912	1144	1377	1609
187	271342	2074	2306	2538	2770	3001	3233	3464	3696	3927
188	4158	4389	4620	4850	5081	5311	5542	5772	6002	6232
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191	281033	1261	1488	1715	1942	2169	2396	2622	2849	3075
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195	290035	0257	0480	0702	0925	1147	1369	1591	1813	2034
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197	4466	4687	4907	5127	5347	5567	5787	6007	6226	6446
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199	8853	9071	9289	9507	9725	9943	0161	0378	0595	0813

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204	9630	9843	0056	0268	0481	0693	0906	1118	1330	1542
205	311754	1966	2177	2389	2600	2812	3023	3234	3445	3656
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207	5970	6180	6390	6599	6809	7018	7227	7436	7646	7854
208	8063	8272	8481	8689	8898	9106	9314	9522	9730	9938
209	320146	0354	0562	0769	0977	1184	1391	1598	1805	2012
210	2219	2426	2633	2839	3046	3252	3458	3665	3871	4077
211	4282	4488	4694	4899	5105	5310	5516	5721	5926	6131
212	6356	6541	6745	6950	7155	7359	7563	7767	7972	8176
213	8380	8583	8787	8991	9194	9398	9601	9805	0008	0211
214	330414	0617	0819	1022	1225	1427	1630	1832	2034	2236
215	2438	2640	2842	3044	3246	3447	3649	3850	4051	4253
216	4454	4655	4856	5057	5257	5458	5658	5859	6059	6260
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218	8456	8656	8855	9054	9253	9451	9650	9849	0047	0246
219	340444	0642	0841	1039	1237	1435	1632	1830	2028	2225
220	2423	2620	2817	3014	3212	3409	3606	3802	3999	4196
221	4392	4589	4785	4981	5178	5374	5570	5766	5962	6157
222	6353	6549	6744	6939	7135	7330	7525	7720	7915	8110
223	8305	8500	8694	8889	9083	9278	9472	9666	9860	0054
224	350248	0442	0636	0829	1023	1216	1410	1603	1796	1989
225	2183	2375	2568	2761	2954	3147	3339	3532	3724	3916
226	4108	4301	4493	4685	4876	5068	5260	5452	5643	5834
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235	371068	1253	1437	1622	1806	1991	2175	2360	2544	2728
236	2912	3096	3280	3464	3647	3831	4015	4198	4382	4565
237	4748	4932	5115	5298	5481	5664	5846	6029	6212	6394
238	6577	6759	6942	7124	7306	7488	7670	7852	8034	8216
239	8398	8580	8761	8943	9124	9306	9487	9668	9849	0030
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242	3815	3995	4174	4353	4533	4712	4891	5070	5249	5428
243	5606	5785	5964	6142	6321	6499	6677	6856	7034	7212
244	7390	7568	7746	7923	8101	8279	8456	8634	8811	8989
245	9166	9343	9520	9698	9875	0051	0228	0405	0582	0759
246	390935	1112	1288	1464	1641	1817	1993	2169	2345	2521
247	2697	2873	3048	3224	3400	3575	3751	3926	4101	4277
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253	3121	3292	3464	3635	3807	3978	4149	4320	4492	4663
254	4834	5005	5176	5346	5517	5688	5858	6029	6199	6370
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258	411620	1788	1956	2124	2293	2461	2629	2796	2964	3132
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264	421604	1768	1933	2097	2261	2426	2590	2754	2918	3082
265	3246	3410	3574	3737	3901	4065	4228	4392	4555	4718
266	4882	5045	5208	5371	5534	5697	5860	6023	6186	6349
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275	9333	9491	9648	9806	9964	0122	0279	0437	0594	0752
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277	2480	2637	2793	2950	3106	3263	3419	3576	3732	3889
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283	1786	1940	2093	2247	2400	2553	2706	2859	3012	3165
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289	460898	1048	1198	1348	1499	1649	1799	1948	2098	2248
290	2398	2548	2697	2847	2997	3146	3296	3445	3594	3744
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296	471292	1438	1585	1732	1878	2025	2171	2318	2464	2610
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305	4300	4442	4585	4727	4869	5011	5153	5295	5437	5579
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312	4155	4294	4433	4572	4711	4850	4989	5128	5267	5406
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315	8311	8448	8586	8724	8862	8999	9137	9275	9412	9550
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317	501059	1196	1333	1470	1607	1744	1880	2017	2154	2291
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321	6505	6640	6776	6911	7046	7181	7316	7451	7586	7721
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323	9203	9337	9471	9606	9740	9874	0009	0143	0277	0411
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325	1883	2017	2151	2284	2418	2551	2684	2818	2951	3084
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327	4548	4681	4813	4946	5079	5211	5344	5476	5609	5741
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330	8514	8646	8777	8909	9040	9171	9303	9434	9566	9697
331	9828	9959	0090	0221	0353	0484	0615	0745	0876	1007
332	521138	1269	1400	1530	1661	1792	1922	2053	2183	2314
333	2444	2575	2705	2835	2966	3096	3226	3356	3486	3616
334	3746	3876	4006	4136	4266	4396	4526	4656	4785	4915
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339	530200	0328	0456	0584	0712	0840	0968	1096	1223	1351
340	1479	1607	1734	1862	1990	2117	2245	2372	2500	2627
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343	5294	5421	5547	5674	5800	5927	6053	6180	6306	6432
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346	9076	9202	9327	9452	9578	9703	9829	9954	0079	0204
347	540329	0455	0580	0705	0830	0955	1080	1205	1330	1454
348	1579	1704	1829	1953	2078	2203	2327	2452	2576	2701
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358	3883	4004	4126	4247	4368	4489	4610	4731	4852	4973
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364	561101	1221	1340	1459	1578	1698	1817	1936	2055	2174
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366	3481	3600	3718	3837	3955	4074	4192	4311	4429	4548
367	4666	4784	4903	5021	5139	5257	5376	5494	5612	5730
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381	580925	1039	1153	1267	1381	1495	1608	1722	1836	1950
382	2063	2177	2291	2404	2518	2631	2745	2858	2972	3085
383	3199	3312	3426	3539	3652	3765	3879	3992	4105	4218
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389	9950	0061	0173	0284	0396	0507	0619	0730	0842	0953
390	591065	1176	1287	1399	1510	1621	1732	1843	1955	2066
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393	4393	4503	4614	4724	4834	4945	5055	5165	5276	5386
394	5496	5606	5717	5827	5937	6047	6157	6267	6377	6487
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397	8791	8900	9009	9119	9228	9337	9446	9556	9665	9774
398	9883	9992	0101	0210	0319	0428	0537	0646	0755	0864
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402	4226	4334	4442	4550	4658	4766	4874	4982	5089	5197
403	5305	5413	5521	5628	5736	5844	5951	6059	6166	6274
404	6381	6489	6596	6704	6811	6919	7026	7133	7241	7348
405	7455	7562	7669	7777	7884	7991	8098	8205	8312	8419
406	8526	8633	8740	8847	8954	9061	9167	9274	9381	9488
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408	610660	0767	0873	0979	1086	1192	1298	1405	1511	1617
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411	3842	3947	1053	4159	4264	4370	4475	4581	4686	4792
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414	7000	7105	7210	7315	7420	7525	7629	7734	7839	7943
415	8048	8153	8257	8362	8466	8571	8676	8780	8884	8989
416	9093	9198	9302	9406	9511	9615	9719	9824	9928	0032
417	620136	0240	0344	0448	0552	0656	0760	0864	0968	1072
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419	2214	2318	2421	2525	2628	2732	2835	2939	3042	3146
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421	4282	4385	4488	4591	4695	4798	4901	5004	5107	5210
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427	630428	0530	0631	0733	0835	0936	1038	1139	1241	1342
428	1444	1545	1647	1748	1849	1951	2052	2153	2255	2356
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432	5484	5584	5685	5785	5886	5986	6087	6187	6287	6388
433	6488	6588	6688	6789	6889	6989	7089	7189	7290	7390
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437	640481	0581	0680	0779	0879	0978	1077	1177	1276	1375
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439	2465	2563	2662	2761	2860	2959	3058	3156	3255	3354
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443	6404	6502	6600	6698	6796	6894	6992	7089	7187	7285
444	7383	7481	7579	7676	7774	7872	7969	8067	8165	8262
445	8360	8458	8555	8653	8750	8848	8945	9043	9140	9237
446	9335	9432	9530	9627	9724	9821	9919	0016	0113	0210
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448	1278	1375	1472	1569	1666	1762	1859	1956	2053	2150
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452	5138	5235	5331	5427	5526	5619	5715	5810	5906	6002
453	6098	6194	6290	6386	6482	6577	6673	6769	6864	6960
454	7056	7152	7247	7343	7438	7534	7629	7725	7820	7916
455	8011	8107	8202	8298	8393	8488	8584	8679	8774	8870
456	8965	9060	9155	9250	9346	9441	9536	9631	9726	9821
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459	1813	1907	2002	2096	2191	2286	2380	2475	2569	2663
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462	4642	4736	4830	4924	5018	5112	5206	5299	5393	5487
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465	7453	7546	7640	7733	7826	7920	8013	8106	8199	8293
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467	9317	9410	9503	9596	9689	9782	9875	9967	0060	0153
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469	1173	1265	1358	1451	1543	1636	1728	1821	1913	2005
470	2098	2190	2283	2375	2467	2560	2652	2744	2836	2929
471	3021	3113	3205	3297	3390	3482	3574	3666	3758	3850
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473	4861	4953	5045	5137	5228	5320	5412	5503	5595	5687
474	5778	5870	5962	6053	6145	6236	6328	6419	6511	6602
475	6694	6785	6876	6968	7059	7151	7242	7333	7424	7516
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478	9428	9519	9610	9700	9791	9882	9973	0063	0154	0245
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480	1241	1332	1422	1513	1603	1693	1784	1874	1964	2055
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482	3047	3137	3227	3317	3407	3497	3587	3677	3767	3857
483	3947	4037	4127	4217	4307	4396	4486	4576	4666	4756
484	4845	4935	5025	5114	5204	5294	5383	5473	5563	5652
485	5742	5831	5921	6010	6100	6189	6279	6368	6458	6547
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487	7529	7618	7707	7796	7886	7975	8064	8153	8242	8331
488	8420	8509	8598	8687	8776	8865	8953	9042	9131	9220
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492	1965	2053	2142	2230	2318	2406	2494	2583	2671	2759
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494	3727	3815	3903	3991	4078	4166	4254	4342	4430	4517
495	4605	4693	4781	4868	4956	5044	5131	5219	5307	5394
496	5482	5569	5657	5744	5832	5919	6007	6094	6182	6269
497	6356	6444	6531	6618	6706	6793	6880	6968	7055	7142
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517	3491	3575	3659	3742	3826	3910	3994	4078	4162	4246
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537	9974	0055	0136	0217	0298	0378	0459	0540	0621	0702
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562	9736	9814	9891	9968	0045	0123	0200	0277	0354	0431
563	750508	0586	0663	0740	0817	0894	0971	1048	1125	1202
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565	2048	2125	2202	2279	2356	2433	2509	2586	2663	2740
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577	1176	1251	1326	1402	1477	1552	1627	1702	1778	1853
578	1928	2003	2078	2153	2228	2303	2378	2453	2529	2604
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624	5185	5254	5324	5393	5463	5532	5602	5672	5741	5811
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627	7268	7337	7406	7475	7545	7614	7683	7752	7821	7890
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633	1404	1472	1541	1609	1678	1747	1815	1884	1952	2021
634	2089	2158	2226	2295	2363	2432	2500	2568	2637	2705
635	2774	2842	2910	2979	3047	3116	3184	3252	3321	3389
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640	6180	6248	6316	6384	6451	6519	6587	6655	6723	6790
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648	1575	1642	1709	1776	1843	1910	1977	2044	2111	2178
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653	4913	4980	5046	5113	5179	5246	5312	5378	5445	5511
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655	6241	6308	6374	6440	6506	6573	6639	6705	6771	6838
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667	4126	4191	4256	4321	4386	4451	4516	4581	4646	4711
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685	5691	5754	5817	5881	5944	6007	6071	6134	6197	6261
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687	6957	7020	7083	7146	7210	7273	7336	7399	7462	7525
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693	0733	0796	0859	0921	0984	1046	1109	1172	1234	1297
694	1359	1422	1485	1547	1610	1672	1735	1797	1860	1922
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697	3233	3295	3357	3420	3482	3544	3606	3669	3731	3793
698	3855	3918	3980	4042	4104	4166	4229	4291	4353	4415
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702	6337	6399	6461	6523	6585	6646	6708	6770	6832	6894
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704	7573	7634	7696	7758	7819	7881	7943	8004	8066	8128
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707	9419	9481	9542	9604	9665	9726	9788	9849	9911	9972
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711	1870	1931	1992	2053	2114	2175	2236	2297	2358	2419
712	2480	2541	2602	2663	2724	2785	2846	2907	2968	3029
713	3090	3150	3211	3272	3333	3394	3455	3516	3577	3637
714	3698	3759	3820	3881	3941	4002	4063	4124	4185	4245
715	4306	4367	4428	4488	4549	4610	4670	4731	4792	4852
716	4913	4974	5034	5095	5156	5216	5277	5337	5398	5459
717	5519	5580	5640	5701	5761	5822	5882	5943	6003	6064
718	6124	6185	6245	6306	6366	6427	6487	6548	6608	6668
719	6729	6789	6850	6910	6970	7031	7091	7152	7212	7272
720	7332	7393	7453	7513	7574	7634	7694	7755	7815	7875
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727	1534	1594	1654	1714	1773	1833	1893	1952	2012	2072
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734	5696	5755	5814	5874	5933	5992	6051	6110	6169	6228
735	6287	6346	6405	6465	6524	6583	6642	6701	6760	6819
736	6878	6937	6996	7055	7114	7173	7232	7291	7350	7409
737	7467	7526	7585	7644	7703	7762	7821	7880	7939	7998
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316	1690	1743	1797	1850	1903	1956	2009	2063	2116	2169
317	2222	2275	2323	2381	2435	2488	2541	2594	2647	2700
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952	8637	8683	8728	8774	8819	8865	8911	8956	9002	9047
953	9093	9138	9184	9230	9275	9321	9366	9412	9457	9503
954	9548	9594	9639	9685	9730	9776	9821	9867	9912	9958
955	980003	0049	0094	0140	0185	0231	0276	0322	0367	0412
956	0458	0503	0549	9594	0640	0685	0730	0776	0821	0867
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958	1366	1411	1456	1501	1547	1592	1637	1683	1728	1773
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962	3175	3220	3265	3310	3356	3401	3446	3491	3536	3581
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966	4977	5022	5067	5112	5157	5202	5247	5292	5337	5382
967	5426	5471	5516	5561	5606	5651	5699	5741	5786	5830
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970	6772	6817	6861	6906	6951	6996	7040	7085	7130	7175
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973	8113	8157	8202	8247	8291	8336	8381	8425	8470	8514
974	8559	8604	8648	8693	8737	8782	8826	8871	8916	8960
975	9005	9049	9094	9138	9183	9227	9272	9316	9361	9405
976	9450	9494	9539	9583	9628	9672	9717	9761	9806	9850
977	9895	9939	9983	0028	0072	0117	0161	0206	0250	0294
978	990339	0383	0428	0472	0516	0561	0605	0650	0694	0738
979	0783	0827	0871	0916	0960	1004	1049	1093	1137	1182
980	1226	1270	1315	1359	1403	1448	1492	1536	1580	1625
981	1669	1713	1758	1802	1846	1890	1935	1979	2023	2067
982	2111	2156	2200	2244	2288	2333	2377	2421	2465	2509
983	2554	2598	2642	2686	2730	2774	2819	2863	2907	2951
984	2995	3039	3083	3127	3172	3216	3260	3304	3348	3392
985	3436	3480	3524	3568	3613	3657	3701	3745	3789	3833
986	3877	3921	3965	4009	4053	4097	4141	4185	4229	4273
987	4317	4361	4405	4449	4493	4537	4581	4625	4669	4713
988	4757	4801	4845	4889	4933	4977	5021	5065	5108	5152
989	5196	5240	5284	5328	5372	5416	5460	5504	5547	5591
990	5635	5679	5723	5767	5811	5854	5898	5942	5986	6030
991	6074	6117	6161	6205	6249	6293	6337	6380	6424	6468
992	6512	6555	6599	6643	6687	6731	6774	6818	6862	6906
993	6949	6993	7037	7080	7124	7168	7212	7255	7299	7343
994	7386	7430	7474	7517	7561	7605	7648	7692	7736	7779
995	7823	7867	7910	7954	7998	8041	8085	8129	8172	8216
996	8259	8303	8347	8390	8434	8477	8521	8564	8608	8652
997	8695	8739	8782	8826	8869	8913	8956	9000	9043	9087
998	9131	9174	9218	9261	9305	9348	9392	9435	9479	9522
999	9565	9609	9652	9696	9739	9783	9826	9870	9913	9957

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